FINAL REPORT

DEVELOPMENT PROGRAM FOR IMPROVING FOUNDRY AND REPAIR WELDING TECHNIQUES FOR ZE41 – TYPE MAGNESIUM ALLOY CASTINGS

By

JAYDEV DESAI

September 1976

CONTRACT NO: DAAA-25-75-C-0599

PITMAN – DUNN LABORATORY, FRANKFORD ARSENAL
PHILADELPHIA, PA 19137

WORK DONE BY
HITCHCOCK INDUSTRIES INC.
MINNEAPOLIS, MINNESOTA

FOR

U. S. ARMY AVIATIONS SYSTEMS COMMAND
ST. LOUIS, MO 63116
PROJECT MANAGER – J. M. THORP

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Development Program for Improving Foundry and Repair Welding Techniques for ZE41-type Magnesium Alloy Castings.	5. TYPE OF REPORT & PERIOD COVERED Final Report July 1975 to June 1976
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jaydev Desai, Hitchcock Industries Inc.	8. CONTRACT OR GRANT NUMBER(s) DAAA-25-75-C0599
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hitchcock Industries Inc. 8701 Harriet Avenue South Minneapolis, Minnesota 55420	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Aviation Systems Command P.O. Box 209, Main Post Office St. Louis, Missouri 63116	12. REPORT DATE September 1976
	13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Pitman - Dunn Laboratory L3100 Frankford Arsenal Philadelphia, PA 19137	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for Public Release; Distribution Unlimited.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Magnesium Alloys
Castings
ZE41 Alloy
Aircraft - Quality Castings
Tensile Properties
Repair Welding
Weld Cracking

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a development program for improved foundry and repair welding techniques for large complex ZE41-type magnesium castings, such as currently specified by the designers of next generation of army aircraft (e.g. the AAH, UTTAS, etc.). This one year program was directed at resolving the weld cracking problem in ZE41 magnesium alloy combiner housing casting for the HLH aircraft, and making it a high quality reproducible part.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT (CONT'D)

It was verified in this program that the tendency towards weld cracking increases with an increase in zinc content and a decrease in rare earth content in ZE41-type magnesium alloys. Zinc increases the tensile strength and yield strength and reduces elongation for a given rare earth content, while the rare earth component improves the weldability but reduces tensile properties. Within ZE41 range, low zinc and high rare earth content had the best weldability but the lowest tensile properties. The results showed that a chemical composition between that of EZ33 and ZE41 was less prone to weld cracking as compared to ZE41, but such an alloy had lower tensile properties than ZE41 alloy. The tensile properties of ten (10) different chemical compositions (six in ZE41 range and four between EZ33 and ZE41), resulting from various heat treatments examined in this program, were similar. Deterioration of tensile properties with prolonged heat treatments was not observed up to twenty (20) hours at 625° F and twelve (12) hours at 675° F. This stability of properties indicate that ZE41-type castings can withstand several preheating, welding, and post heat treating cycles without deteriorating the tensile properties.

The results on one HLH combiner housing casting poured with a chemical composition between that of EZ33 and ZE41 alloys, showed that the tensile properties of the machined test bars taken from various section thicknesses and chill/riser/neutral locations were similar, and that the tensile properties of welded and nonwelded areas were comparable. Two step heat treatment (625° F or 675° F for two (2) hours, air cool, 340° F for twelve (12) hours) provided effective stress relief. Thus for large complicated magnesium castings, such as the HLH combiner housing, the cracking in the weld areas during welding as well as delayed cracking in the weld areas can be overcome by the proper selection of chemical composition and heat treatment.

CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

I. INTRODUCTION

The objective of this work was to develop foundry and repair welding techniques for producing sound ZE41-type magnesium castings. The program utilized commercially available materials and existing foundry equipment. Industrial experience with large magnesium alloy castings over the past several years has revealed certain problem areas, especially in the case of complicated ZE41 magnesium alloy castings, such as currently specified by the designers of the next generation of army aircraft (e.g. the AAH, UTTAS, etc.). This one year program was directed at making the ZE41 magnesium alloy combiner housing for the HLH aircraft, a reproducible high quality part, utilizing the latest R & D information on magnesium casting practice and the industrial experience with combiner housing. The goal was to determine an optimum combination of chemical composition and heat treatment which will provide castability, adequate strength and ductility and resistance to weld cracking.

The parameters studied in terms of such castings included:

1. Alloy composition - to obtain the optimum combination of strength and resistance to cast and weld cracking.

   Rare earth component reduces microporosity and hot tearing tendency and improves weldability. (1) Increase in rare earth content reduces tensile strength and elongation. (1) Increase in zinc content increases tensile strength and yield strength and reduces elongation. (1) Thus, because of the difficult balance required between tensile properties, castability and weldability a systematic variation of composition was studied across the range of ZE41 alloy and across the gap between EZ33 and ZE41. Ranges of zinc and rare earth for EZ33 and ZE41 are schematically shown in Figure 1. The chemical compositions were selected based on factorial experimental design principles. This included several zinc levels at each of several rare earth levels, such that trends can be seen. Selected chemical compositions are shown in Table I.

2. Stress relief heat treatment - to avoid cracking and yet retain sufficiently high strength.

   The reported detrimental effect of extensive stress-relief treatments on mechanical properties was evaluated for various chemical compositions. Selected heat treatments are shown in Table II.

   Aerospace Material Specification (AMS) 4439 was used as a reference specification for ZE41 alloy in this program. The chemical composition and mechanical property requirements per this specification are given in Table III.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The experimental procedure was designed to conduct a series of tests on separately cast test bars, test plates and full size HLH combiner housing in order to determine optimum conditions for casting and welding complicated aircraft quality castings in ZE41 or from across the gap between EZ33 and ZE41.

A standard sand-cast, four tensile bar mold was used for separately cast bars. They are standard RI-.505 diameter test bars per method 211 of MIL-STD-151 tested unmachined. They were cast in green sand molds and a photograph of test bars with gates and risers attached is shown in Figure 2.

A test plate was designed with eight (8) areas representing typical weld repairs encountered in practice. This included various section thicknesses (thin- 3/16", intermediate- 3/4" and thick- 1/2") and different constraints and sizes for each thickness. Figure 3 shows the dimensional details for the test plate. The test plate was mounted on a wood board pattern and the gating and risering system was affixed. Figure 4 shows the test plate with gates and risers attached.

HLH combiner housing casting was made using the dry sand pattern equipment consisting of 93 core boxes. Figures 5 and 6 show the casting with gates and risers attached.

A. PHASE I: TEST BARS AND TEST PLATES

Melting and Pouring:

The metal was prepared from alloyed EZ33 or ZE41 ingots, foundry returns (gates, risers and scrap castings) and alloying elements (pure zinc, pure magnesium, rare earth as Mischaloy and zirconium as Zirmax), using standard melting and alloying procedure recommended by Magnesium Electron. (1) Various chemical compositions are shown in Table I. The following variables, which can have a major effect on chemical analysis, mechanical properties and internal and surface defects were closely controlled and maintained fairly constant for all ten melts.

1. Alloying temperature - 1450° F.
2. Time duration between alloying and pouring - 1 to 2 hours.
3. Zirconium grain refinement checked by fracturing one inch diameter by twelve inches long fracture bars poured in cast iron mold.
4. Pouring temperature - 1500° F.
5. Pouring time - 8 to 9 seconds for test plates and 5 seconds for test bars.
6. Pouring distance from the mold.
7. Time duration between pouring and shake out - 30 minutes.

The data was recorded on a record sheet for all ten melts. All molds were made using green sand with regular foundry additives for magnesium. An attempt was made to keep the chemical composition as close to the nominal as possible. Actual chemical analysis of all ten melts is shown in Table IV. Degree of grain refinement was checked, prior to pouring,

using one inch diameter fracture bars. Zirconium was maintained at the same level for all ten melts to avoid large variation in grain size. Grain size is a major factor for mechanical properties of zirconium containing magnesium alloys. Contamination with elements such as iron, aluminum, etc., which are detrimental to zirconium grain refining was avoided. A typical photomicrograph of the polished section of a fracture bar is shown in Figure 7. The fracture bars from all ten melts had similar microstructure and grain size. A higher initial pouring temperature of 1500° F was used for test plates and test bars to account for the decrease in molten metal temperature because of heat losses that will occur in pouring thirty six (36) molds. (28 test bar molds plus 8 test plate molds.)

Separately cast test bars were grouped to minimize the effect of variables such as pouring temperature, mold material, etc. There were twenty eight (28) test bar molds in each melt, each mold having four test bars. These were divided into four groups of seven molds each. Groups were numbered 1, 2, 3 and 4, which indicates the order of pouring and hence a slight decrease in pouring temperature because of heat losses from the pot of molten metal while pouring. The following identification marking was used.

4-9435-X-H1

Same for all test bars and test plates.	Melt number varies from 1 to 10 for 10 different melts.	Heat treat lot number varies from 1 to 8 for 8 different heat treatments.

On any melt X, 4-9435-X-H1 will consist of four test bars from groups 1, 2 and 3 described above. 4-9435-X-H2 will consist of four test bars from groups 4, 1 and 2 and so on. This will minimize the effect of variation in pouring temperature from mold 1 to 28. Thus, for any melt (X) heat treat (Y) combination, there were twelve test bars from three different molds as selected above. Two test bars from each of these three molds were used for welding as described in the next section, and the remaining six bars were not welded. This will minimize the effect of variation in molding sand and mold variables.

Eight test plates for each melt were numbered 1 to 8 in order of pouring. On any melt X, number 1 plate will be 4-9435-X-H1, number 2 will be 4-0435-X-H2 and so on. Melt and heat treat numbers were steel stamped on test bars and test plates right after pouring to maintain tracability.

From each melt two standard spectrographic discs were poured (one before pouring and one after pouring) and analysis was conducted per ASTM-E-2. The results were recorded and identified by melt number. Chemical analysis of actual melts poured is shown in Table IV.

Welding:

Test plates and half of the separately cast test bars were welded as follows.

Grooves were machined on all the separately cast test bars to maintain con-

sistency in size and location of the weld area. The grooves were machined on the cope side of all the test bars. Figure 8 is a sketch of the test bar used for welding.

On each test plate, eight areas were welded. Optimum preheat temperature, best welding procedure and the sequence of welding eight welds on each test plate were established by experimenting on preliminary test plates, prior to the welding of test plates on the test program.

Preheat temperature:

No preheat and preheat temperature of 400° F and 600 ° F were tried. Weld quality was examined by zyglo and x-ray. Best results were obtained with 600° F preheat. Preheat time required to reach the temperature of 600° F in the thinnest section of the test plate was approximately thirty (30) minutes.

Through thickness weld:

The following were tried: No back-up material, mild-steel back-up and carbon back-up. Carbon back-up gave best results.

Sequence of welding:

The sequence of welding eight welds was determined on the basis of ease of welding a particular area (determined by thickness and location of the area for a given composition) and maintaining favorable heat flow to get enough temperature in the last area to be welded. Weld area identification numbers in Figure 19 also indicate the sequence of welding eight welds, weld number 1 being the first area welded, weld number 2 being the second area welded, and so on.

The same welding procedure, preheat time and temperature, and sequence of welding eight welds were maintained for all test plates. Weld areas for all the test plates were prepared by routing surface oxides using rotary cutters. Size of each weld was maintained reasonably constant from plate to plate. The test plates and test bars were vapor degreased prior to welding and were welded on the same day to prevent the surface from getting oxidized. All the weld areas were welded using extruded ZE41 weld rods with the following chemical composition: zinc - 4.20%, rare earth - 1.60%, zirconium - 0.52%. All the welded areas were cleaned and blended after welding.

Nondestructive Testing Of Weld Areas:

Welded areas of test plates were examined using fluorescent penetrant. Fluorescent penetrant inspection of the welded areas was also performed after heat treatment to identify the effect of eight different heat treatments on all ten melts. After heat treatment test plates and test bars were examined radiographically per MIL-STD-453. Three separate exposures were made for three different thicknesses of each test plate. Test bars were x-rayed for reduced section only. All exposures were made using ZE41 penetrameters and the films were identified with identification marking explained before. Defects found in the weld areas of the test plates (see Figure 19 and Table VI) during radiographic inspection are

given in Table V.

Heat Treatments:

Time-temperatures for eight different heat treatments are given in Table II. Two step heat treatment (designated H1 in Table II) is recommended by Magnesium Electron for ZE41 magnesium alloy. (1,2) Other heat treatments with longer time and higher temperature were examined to see the effect of prolonged heat treatments on tensile properties. They were also used to simulate repeated preheating and post heat treatment encountered during repeated welding. Steps were taken to ensure identical temperature conditions for different heat treat loads. Time and temperatures were recorded on charts using an automatic recorder.

Mechanical Testing:

Separately cast test bars:

Five welded and five nonwelded test bars were tested for all eighty (80) melt-heat combination (10 melts x 8 heat treatments = 80). In all, 800 separately cast test bars were tested, which included 400 welded and 400 nonwelded test bars. The testing was done for tensile, yield and elongation at room temperature per ASTM-E-8 using an automatic recorder on the tensile tester. One welded and one nonwelded test bar are being retained for further testing as necessary. The results for separately cast bars are shown in Table VII.

Test Plates:

Tensile testing was done on all ten melts, each melt consisting of eight test plates representing eight different heat treatments. Test bars were machined from welded and nonwelded areas of test plates for all three thicknesses (thin - 3/16", intermediate - 3/4", and thick - 1 1/2") and tested for tensile, yield and elongation (see Figure 20 and Table IX). All the tensile specimens were flat, 1 inch gage length specimen dimensioned half size to F2 of method 211.1 of Federal Test Method Standard number 151. The location of the machined test bars from cast or welded surface was maintained constant for all test plates to minimize the variation in mechanical properties with distance from the cast or welded surface. The tensile testing was done at room temperature per ASTM-E-8 using an automatic recorder on the test instrument.

Tensile properties for machined test bars from test plates are shown in Table VIII, along with Brinell hardness (500 kg load and 10 mm ball).

B. PHASE II: HLH COMBINER HOUSING CASTING

Data from the phase I of the program were analyzed to determine chemical composition and heat treatment for optimum combination of tensile properties and weldability. The folowing chemical composition was selected: Zinc - 3.0 - 3.5%, Rare Earth - 1.8 - 2.2% and Zirconium - 0.7 - 0.9%.

HLH Main Combiner Transmission Housing was poured and processed as shown in Figure 9.

Two different melting pots were used because of the large amount of metal

required. The average chemical composition of the two pots was:

Zinc - 3.19%
Rare Earth - 2.06%
Zirconium - 0.72%
Balance - Magnesium and impurities.

The casting was poured at 1450° F. The weight of the casting with gates and risers was approximately 1,000 pounds.

After preliminary fluorescent penetrant inspection, all the defects were removed and recorded. Radiographic inspection did not reveal any additional defect, except scattered areas of segreagation. The casting was cut into two halves and weld areas were cut out to have identical locations and sizes on both the halves. (See Figures 10 and 11 and Table XII) All areas were welded using extruded EZ33 weld rods because the chemical composition of the casting was closer to EZ33 alloy. The chemical composition of EZ33 weld rod was: Zinc - 2.20%, Rare Earth - 3.20%, and Zirconium - 0.56%. Extruded ZE41 weld rods were used in the Phase I of the program for welding of test plates on all ten (10) melts to get comparable data. A maximum preheat temperature of 600° F was used, wherever necessary. Sixteen (16) areas were welded on each section with welds varying in size and complexity. The casting was allowed to cool in air after welding. Weld areas were cleaned and dye checked. Small hair-line cracks were detected in two areas (one in each half) after preliminary dye check. Welds were examined radiographically and all welds were acceptable. Thus routing and rewelding of the same weld area was necessary. Two halves (designated section A and section B.) were heat treated as follows:

Section A: 625° F - 2 hours
Air cool
340° F - 12 hours

Section B: 675° F - 2 hours
Air cool
340° F - 12 hours

Heat treatment used for section A (designated H1 in Table II) is the one recommended by Magnesium Electron for ZE41 magnesium alloy (1,2). A higher temperature first step of 675° F was used for section B, which might relieve more residual stresses. Section A was retained to observe any delayed cracking, because it was more likely to exhibit delayed cracking than section B. Section B was used for evaluation of tensile properties.

After heat treatment both halves were inspected visually and with fluorescent penetrant, and all weld areas were found to be satisfactory.

Test bar locations for evaluation of tensile properties were marked on section B (See Figures 12 to 15 and Table XIII). Test locations were selected as follows:

1. Thin, thick and average nonwelded areas.
2. Thin, thick and average welded areas.
3. Areas with segregation detected in x-ray.

Section thickness and riser/chill/neutral location of each test bar were recorded and is shown in Table X, along with tensile properties, (tensile strength, yield strength and % elongation) and Brinell hardness at each location. Tensile testing was done at room temperature per ASTM-E-8, using an automatic recorder on the test instrument.

Section A, which was retained to observe any delayed cracking did not reveal any cracking in the weld areas during visual and fluorescent penetrant inspection after thirty days.

III. DISCUSSION OF RESULTS

A. PHASE I OF THE PROGRAM:

Data from the Phase I of the program were used to determine chemical composition and heat treatment which give optimum combination of weldability and tensile properties. Weldability was determined from the following:

1. Tensile properties of welded bars - both separately cast and machined from test plates.
2. Defects in welded areas of test plates detected during non-destructive testing. (Fluorescent penetrant and x-ray radiography.)

For a given section size, tensile properties of magnesium alloys containing zirconium as a grain refiner, depend mainly on the grain size and also on alloy content, heat treatment and presence of discontinuities, (oxides etc). (1) Grain size is mainly determined by soluble zirconium content, which can be checked by visual observation of grain structure of one inch diameter fracture bar. (1) Grain size was maintained reasonably constant for ten different chemical compositions for the Phase I of the program. Thus the variation in tensile properties will be due to variations in chemical composition, heat treatment and random discontinuities.

As stated before ten different chemical compositions were selected with varying zinc and rare earth contents and each chemical composition was given eight different heat treatments.

Zinc and rare earth are the major alloying elements for EZ33, ZE41 and intermediate zinc-rare earth type magnesium alloys. Zinc increases tensile strength and yield strength slightly, and reduces elongation. (1) Rare earth metals reduce microporosity and hot tearing tendency and make the alloys weldable. (1) Rare earth metals also reduce tensile strength and elongation. (1) Thus zinc improves the strength values while rare earth reduces tensile properties but improves castability and weldability. Thus by varying zinc and rare earth contents, tensile properties, castability and weldability can be varied significantly. The chemical compositions selected in the phase I of the program will exhibit different levels of tensile properties, castability and weldability. In Table I, chemical compositions 4, 5, 6, 7, 8 and 9 are within ZE41 specification, while 1, 2, 3 and 10 are from the gap between EZ33 and ZE41. Chemical composition 10 has higher rare earth than allowed by AMS 4439 specification for ZE41 alloy.

Tensile Properties:

Separately cast test bars: Table VII (nonwelded bars):

In general, ZE41 alloy (chemical compositions 4, 5, 6, 7, 8 and 9) shows higher tensile properties (Approximately 12% higher T.S., 15% higher Y.S. and higher elongation) as compared to alloys from across the gap between EZ33 and ZE41 (chemical compositions 1, 2, 3).

Within the ZE41 range, at the same zinc level, tensile properties decrease

slightly with the increase in rare earth content, as expected. Chemical composition number 2 shows the best, and chemical composition, number 3, the worst tensile properties from melt numbers 1, 2, 3 and 10. (Which are outside ZE41 range).

Machined test bars from test plates: Table VIII (nonwelded bars):

Tensile properties of nonwelded machined test bars from test plates show a trend similar to separately cast bars. Again the tensile properties of ZE41 alloys are higher than the alloys taken from the gap between EZ33 and ZE41 (melt numbers 1, 2, 3 and 10). Chemical composition number 2 shows the best and number 3 the worst tensil properties from melt numbers 1, 2, 3 and 10 (which are outside ZE41 range). Within ZE41 range at the same zinc level, tensile properties decrease slightly with the increase in rare earth content, as expected.

Weldability:

1. Tensile Properties:

Separately cast test bars: Table VII (welded bars):

Withing ZE41 range melt numbers 4 (low zinc and low rare earth) and 5 (low zinc and high rare earth) have the best tensile properties. Melt numbers 6, 7, 8 and 9 have slightly lower tensile strength, similar yield strength and much lower elongation as compared to melt numbers 4 and 5.

Outside ZE41 range, melt number 2 shows the best tensile properties. In general, welded test bars have lower tensile strength and elongation and similar yield strength as compared to nonwelded bars.

Machined test bars from welded test plates: Table VIII (welded bars):

Tensile strength and yield strength of welded test bars are very similar to nonwelded test bars, while % elongation shows a big scatter. At the same zinc level more cracking is observed in alloys with low rare earth content as compared to alloys with high rare earth content. Yield strength of welded test bars is less sensitive to changes in chemical composition than tensile strength and elongation.

Chemical compositions numbers 2 and 5 show consistently high properties for welded test bars and the tensile strength, yield strength and elongation are very similar to nonwelded test bars.

2. Nondestructive Testing:

Fluorescent penetrant inspection and x-ray radiography were used to detect and identify defects (mainly cracks) in the welded areas of test plates. Cracking in the welded areas was the major problem on preproduction HLH combiner housing castings.

Table V summarizes the defects found in the welded areas of test plates.

In general, as would be expected, chemical compositions number 1, 2, 3

(which are from across the gap between EZ33 and ZE41) exhibit less cracking in welded areas as compared to ZE41 alloy (chemical composition numbers 4, 5, 6, 7, 8 and 9). This is because chemical composition numbers 1, 2 and 3 have lower zinc and higher rare earth as compared to ZE41 alloy, and rare earth improves the weldability in these alloys. Within ZE41 range chemical composition number 5 (low zinc and high rare earth within ZE41 specification) gives best weldability, as would be expected. At the same zinc level, weld cracking decreases with increase in rare earth content - compare chemical compositions number 4 and 5, 6 and 7, and 8 and 9. Chemical composition number 2 shows the least tendency for weld cracking.

Optimum Combination Of Weldability And Tensile Properties:

As stated before one of the objectives of the program was to resolve the weld cracking problem on HLH combiner housing casting by varying the chemical composition. As explained before this has to be done at the expense of tensile properties. As discussed in the previous section, chemical composition number 2 showed least tendency for weld cracking from all the chemical compositions selected, while chemical composition number 5 showed least tendency for weld cracking within ZE41 range.

Comparison of tensile properties of chemical compositions number 2 and 5, shows that chemical composition number 2 has approximately 10% lower tensile strength, 12% lower yield strength and 10% lower elongation, for nonwelded separately cast test bars. On nonwelded test bars machined from test plates, chemical composition number 2 shows 3% lower tensile strength, 8% lower yield strength and 18% higher elongation as compared to chemical composition number 5. Thus, chemical composition number 2 exhibits much better weldability (Table V) and slightly lower tensile properties as compared to the optimum chemical composition number 5 within ZE41 range. Hence it was decided to use chemical composition number 2 on HLH combiner housing casting for the phase II of the program:

Zinc - 3.0 - 3.5%
Rare Earth - 1.8 - 2.2%
Zirconium - 0.7 - 0.9%
Balance - magnesium and impurities

The effect of variation in chemical composition (zinc and rare earths) on tensile properties and weldability for zinc-rare earth zirconium type magnesium alloys is schematically shown in Figure 16.

Various heat treatments listed in Table II included a heat treatment (designated H1) recommended for ZE41 alloy by Magnesium Electron Company (1). Other heat treatments were selected to see the effect on tensile properties of prolonged heat treatments as would be encountered in repeated preheating and post heat treating during repeated welding. It is clear that various heat treatments give similar tensile properties, and prolonged exposure at 625° F up to twenty (20) hours and at 675° F up to twelve (12) hours, does not appreciably affect the tensile properties. Within the limits of time and temperatures for various heat treatments it appears that the precipitation hardening process for this type of magnesium alloys is not very sensitive to changes in heat treatment.

B. PHASE II OF THE PROGRAM:

Phase II of the program used the data from the Phase I of the program for the pouring and the processing of HLH combiner housing casting. Excellent weldability of the chemical composition number 2 was established by successful welding of thirty two (32) areas (16 each on each of the two halves) of various complexities - various section thicknesses and various thickness constraints surrounding the weld area. All the welded areas were acceptable per fluorescent penetrant inspection and x-ray radiography, and rewelding of the same area was not necessary. Machined test bars were taken from various section thicknesses and various locations (chill/riser/neutral). In general, tensile properties of the machined test bars from HLH combiner housing are lower than cut test bars from test plates (chemical composition number 2) because of the much larger size of the casting as compared to the test plate (poured weight: HLH combiner housing - 1,000 pounds, test plate - 10 pounds). Tensile properties of machined test bars from HLH combiner housing reveals the following: (See Table X)

1. Tensile properties of test bars taken from different thicknesses and different locations (chill/riser/neutral) are comparable (test bar number 1 through 11, 16 through 20, 23). This means that for sand castings, faster solidification through the use of chills may not improve the tensile properties appreciably (test bar number 35 through 39).

2. Segregation detected in x-ray radiography does not affect the tensile properties significantly as shown by the results on test bar number 21 and 22 (See Table X). These test bars had number 3 segregation based on ASTM-E-155 - reference radiographs for inspection of aluminum and magnesium castings.

3. Tensile properties of test bars cut from welded areas are very similar to nonwelded test bars. (Test bar number 24 through 34). This points to the excellent weldability of the recommended chemical composition.

Photomicrographs of some selected test bars machined from HLH combiner housing are given in Figures 17 and 18. Notice the difference in grain size because of the following factors.

(a) Section thickness: Test bar taken from thin section has finer grain size as compared to test bar taken from thick section.

(b) Location: Test bar taken from chilled section has slightly finer grain size as compared to test bar taken from risered section.

Difference in grain size accounts for the slight difference in tensile properties of different nonwelded test bars in Table X. Extremely fine grain size in the weld area results from the extremely fast solidification rate (instantaneous solidification) of the small mass of molten metal in the weld area.

C. GENERAL DISCUSSION

The following discussion although not directly related to the objective of this program can be helpful to casting designers, quality control personnel and for future review of AMS and other specifications. Most of the comments are based on the results obtained in Phase I and Phase II of the program.

1. Tensile properties of test bars taken from various section thicknesses of the test plates vary slightly, the tensile strength and elongation being affected more than yield strength. However, the tensile properties do not appear to decrease as much with the increase in section thickness, as found in other casting alloys. This is because of the fact that in this type of magnesium alloys, zirconium grain refining is a major determinant of tensile properties. The grain size will be mainly established at the melting stage by the amount of soluble zirconium in the alloy, and will vary only slightly with different solidification rates encountered in different section thicknesses.

2. Room temperature tensile properties are not very sensitive to various heat treatments selected for this program. It appears that for the temperatures investigated, time at which tensile properties might start to decrease was not reached by the selected heat treatments. Tensile properties are stable up to twenty (20) hours at 625° F and up to twelve (12) hours at 675° F.

3. For a given chemical composition, hardness is not very sensitive to different heat treatment times and temperatures, and varies only slightly with chemical compositions. As can be seen from Table VIII, hardness specified for ZE41 alloy by AMS 4439, (Brinell 65 to 80 using 500 kg load), is on the high side. Hardness varies from Brinell 60 to 69, for different heat treatments and chemical compositions for ZE41 alloy.

4. Within ZE41 range, low zinc and high rare earth gives the best weldability. It may be necessary to control the composition near low zinc and high rare earth for expensive castings that must be salvaged by welding. Low zinc and high rare earth range of ZE41 alloy gives the lowest tensile properties obtainable from ZE41 alloy, and the tensile property requirements for both separately cast and machined test bars per AMS 4439 specification may not be met.

5. Tensile properties of machined test bars taken from chill, riser or neutral areas of the HLH combiner housing are comparable. Thus, the tensile properties cannot be changed significantly by chilling (see Table X).

6. There does not appear to be any direct correlation between tensile properties and Brinell hardness (see Table X).

7. The tensile properties of test bars cut from ZE41-type castings will vary with the size and the geometry of the castings, as with all casting alloys. The tensile properties of test bars machined from HLH combiner housing (Table X) are lower than those machined from test plates. (Table VIII, Melt number 2).

8. Test bars machined from areas containing flow-line type of segregation detected in x-ray radiography show properties similar to test bars machined from sound areas of test plates (see Table XI).

9. Some of the separately cast and machined test bars had oxide inclusions in the fractured surface. It appears that small oxide inclusions do not have any detrimental effect on tensile properties. On the other hand, large oxide inclusions will reduce the tensile strength and elongation. In general, magnesium alloys are prone to oxidation during melting and pouring.

10. Welding: Thin areas are more prone to cracking in welding than thick areas. Thin area constrained by heavy sections on both sides is most difficult to weld followed by thin area with heavy section on one and medium section on the other side, followed by thin section on the edge of the casting. For the test plate used in this program weld area number 1 and 2 were most prone to cracking. (See Figure 19).

11. Two step heat treatment (625° F for two (2) hours, air cool, 340° F for twelve (12) hours) provides effective stress relief in ZE41-type castings. Low temperature heat treatment of 480° F for twenty-four (24) hours was not examined in this program, which may give acceptable mechanical properties but could result in less effective stress relief.

12. The creep properties of the alloy selected for pouring of the HLH combiner housing (taken from the gap between EZ33 and ZE41), were not investigated, but they might be better than ZE41 alloy because of higher rare earth content. The creep properties of the selected alloy may be inferior to EZ33 alloy because of lower rare earth content. Rare earth component is responsible for creep properties in this type of magnesium alloys.

IV. CONCLUSIONS

1. It was verified in this program that the tendency towards weld cracking increases with an increase in zinc content and a decrease in rare earth content in ZE41-type magnesium alloys.

2. Zinc increases the tensile strength and yield strength, and reduces elongation for a given rare earth content, while the rare earth component improves the weldability but reduces tensile properties.

3. Within ZE41 range, low zinc and high rare earth content had the best weldability but the lowest tensile properties.

4. One chemical composition taken from the gap between ZE41 and EZ33 magnesium alloys exhibited the best weldability from ten (10) different chemical compositions selected for this program. This alloy (the selected alloy) had better weldability but lower tensile properties than low zinc, high rare earth range of ZE41 alloy.

5. The tensile properties of the selected alloy and other chemical compositions, resulting from various heat treatments, examined in this program were similar. Deterioration of tensile properties with prolonged heat treatments was not observed up to twenty (20) hours at 625° F and twelve (12) hours at 675° F. This stability of properties indicate that ZE41-type castings can withstand several preheating, welding, and post heat treating cycles without deteriorating the tensile properties.

6. Sixteen areas of different complexities were welded on each half of the HLH combiner housing casting without any weld cracking. (Chemical composition of the casting: zinc - 3.19%, rare earth - 2.06% and zirconium - 0.72%). All the weld areas were acceptable per fluorescent penetrant and x-ray radiographic inspection.

7. Average tensile properties of test bars machined from the welded areas of the HLH combiner housing were similar to nonwelded areas.

8. The tensile properties of the selected alloy, taken from various section thicknesses and chill/riser/neutral locations of the HLH combiner housing, were very similar. Thus, for sand castings, increasing the rate of solidification by chilling may not improve the tensile properties significantly.

9. Brinell hardness of the selected alloy ranged from 50 to 60 (500 kg load and 10 mm ball).

10. High temperature heat treatment (Two step process: 625° F or 675° F for two (2) hours, air cool, 340° F for twelve (12) hours) provides effective stress relief in the selected alloy.

11. For large, complicated magnesium castings, such as the HLH combiner housing, the cracking in the weld areas during welding as well as delayed cracking in the weld areas can be overcome by proper selection of chemical composition and heat treatment.

V. RECOMMENDATIONS

1. For large complicated magnesium castings, such as the HLH combiner housing, a chemical composition from across the gap between EZ33 and ZE41 magnesium alloys will be more suitable, because it is less prone to weld cracking as compared to ZE41 magnesium alloy. The following chemical composition is recommended.

	Min.		Max.
Zinc	3.0	-	3.5
Cerium (Total Rare Earths)	1.8	-	2.2
Zirconium (Total)	0.6	-	1.0
Zirconium, Soluble	0.4	-	-
Manganese	-	-	0.15
Copper	-	-	0.10
Nickel	-	-	0.01
Other Impurities (Total)	-	-	0.30
Magnesium	-	-	Remainder

   The tensile properties of this alloy are lower than ZE41 alloy. The alloy can be welded with EZ33 rods, using a preheat temperature of 600° F, when necessary. Two step heat treatment (625° F for two (2) hours, air cool, 340° F for twelve (12) hours) provides adequate stress relief in this alloy.

   This recommendation is based on static tensile properties and weldability. It should be emphasized that the above alloy is recommended for large, complex magnesium castings, where excellent weldability is a major consideration. For most magnesium castings currently designed by the helicopter and aerospace industry, low zinc and high rare earth range of ZE41 alloy gives the best combination of tensile properties and weldability.

2. Issue a new specification for this alloy or study EZ33 and ZE41 alloy specifications to see if the recommended alloy can be incorporated in the specification.

3. Investigate creep and fatigue properties of the recommended alloy.

VI. REFERENCES

1. MEL Foundry Instructions, USNH 73, "The preparation of magnesium - zirconium alloys for sand castings", published by Magnesium Electron LTD, London, England.

2. E. F. Emley, Principles of Magnesium Technology, Pergamon Press, 1966.

FIGURE - 1

SCHEMATIC REPRESENTATION OF ALLOY RANGES

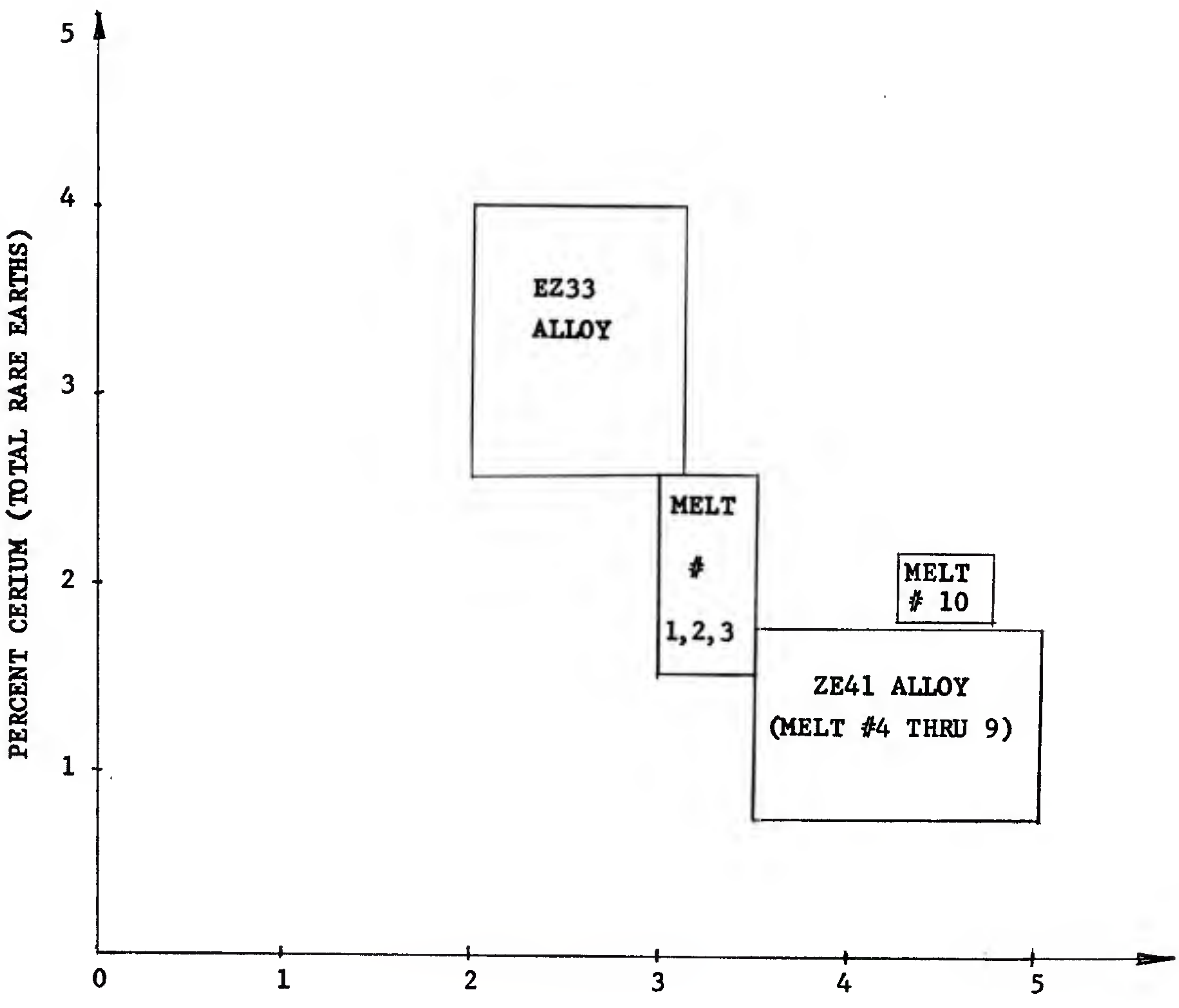


FIGURE - 2

MULTIPLE TEST BARS WITH GATES AND RISERS ATTACHED

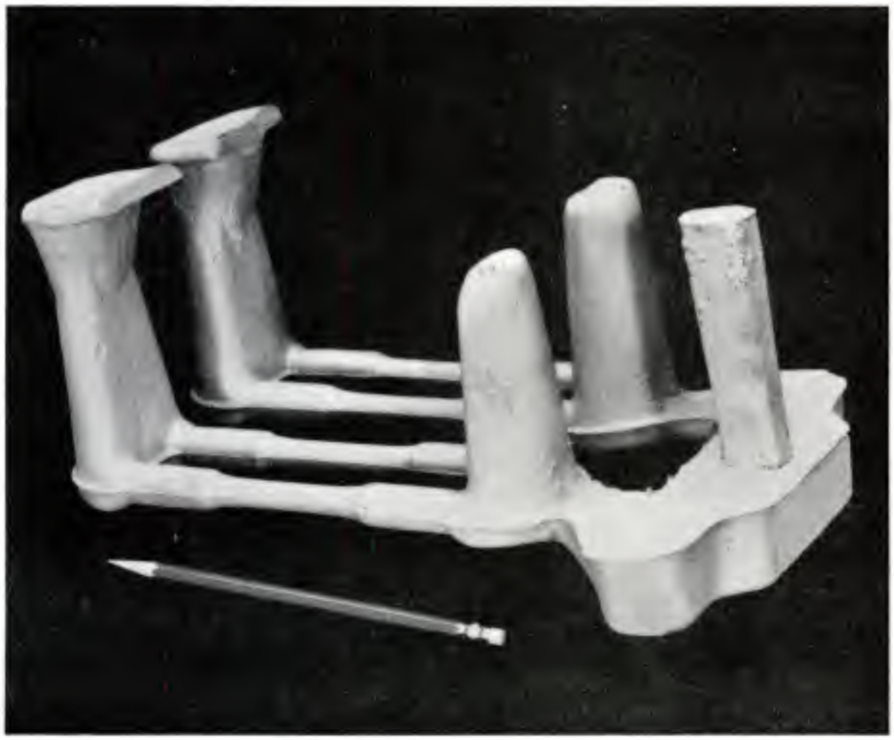


FIGURE - 3

TEST PLATE: DIMENSIONAL SKETCH

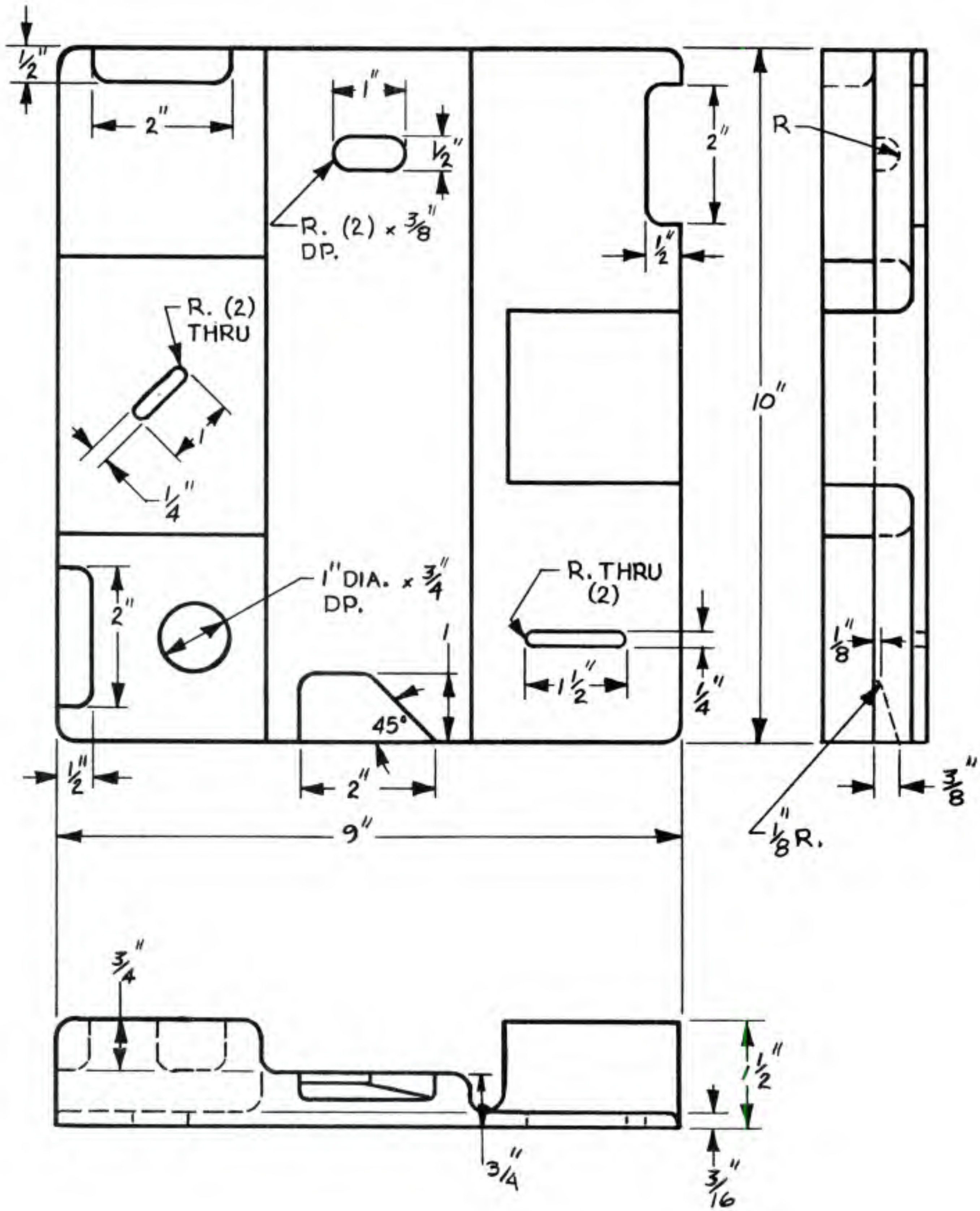
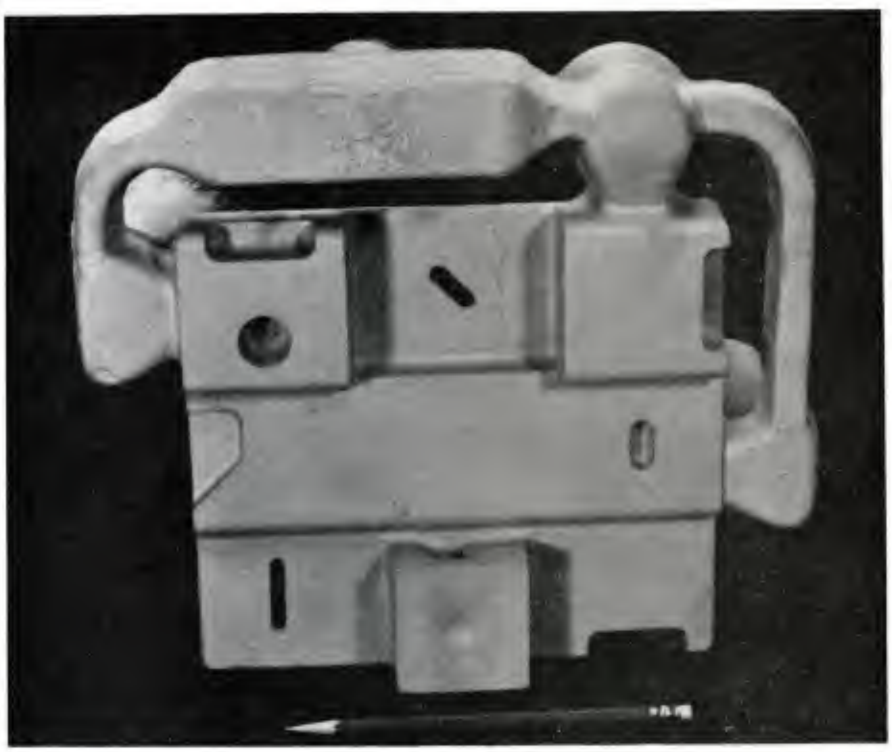


FIGURE - 4

TEST PLATE WITH GATES AND RISERS ATTACHED

COPE VIEW



DRAG VIEW

FIGURE - 5
HLH COMBINER HOUSING CASTING WITH GATES AND RISERS ATTACHED - VIEW 1

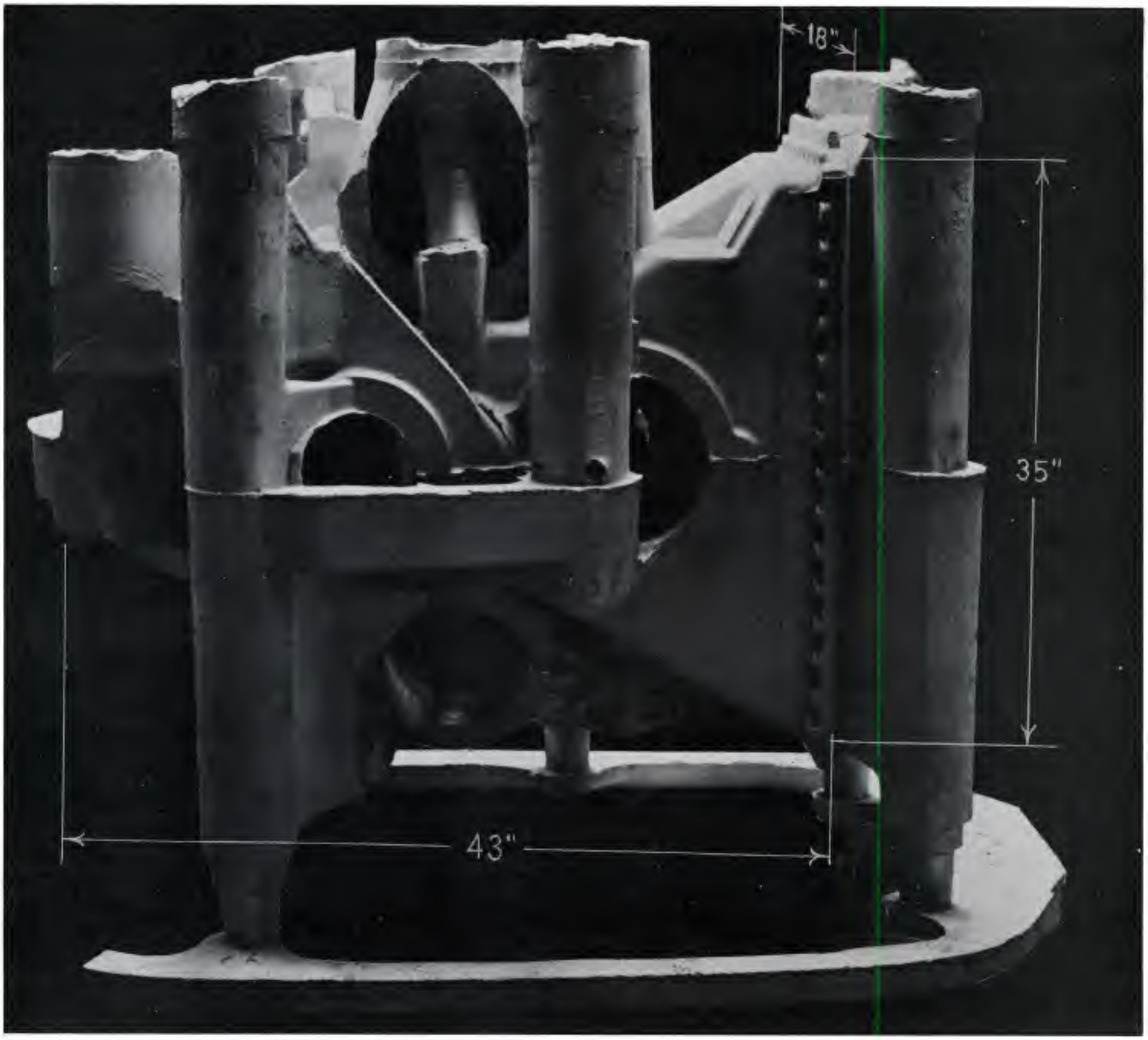


FIGURE - 6

HLH COMBINER HOUSING CASTING WITH GATES AND RISERS ATTACHED - VIEW 2

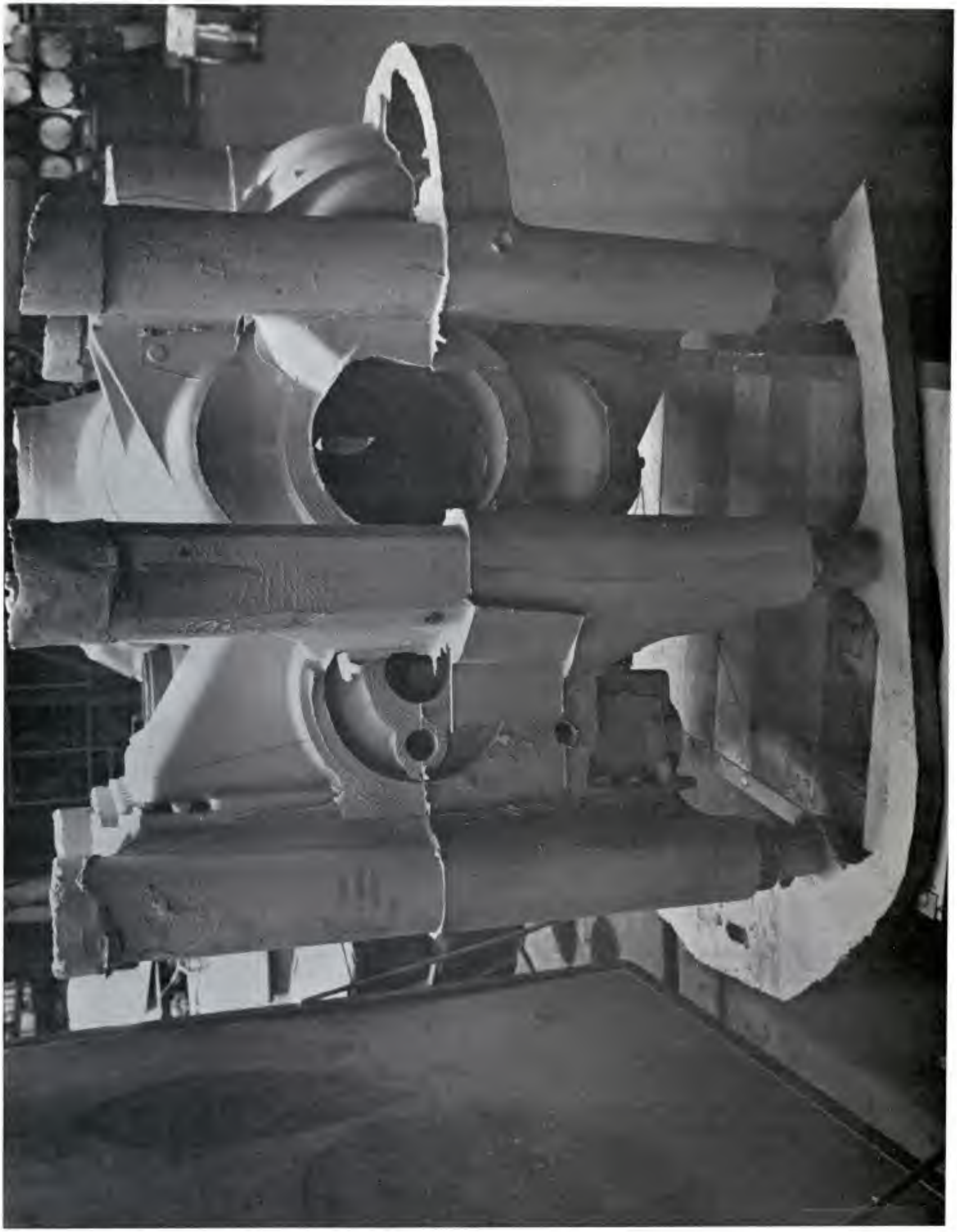
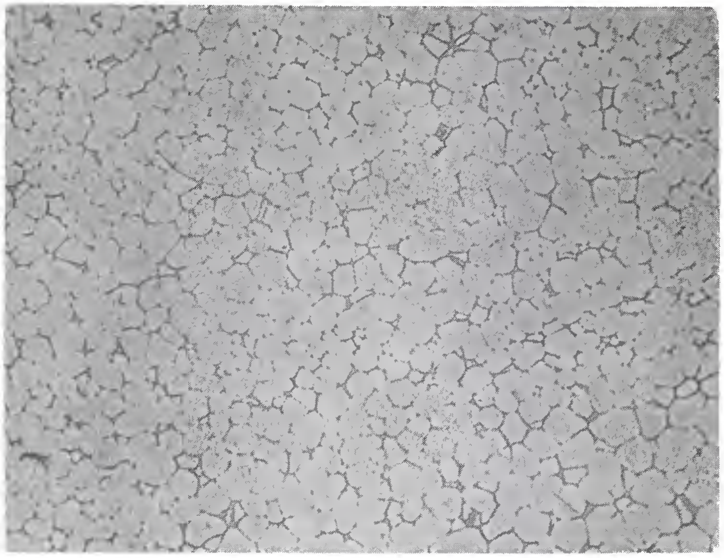


FIGURE - 7

A TYPICAL PHOTOMICROGRAPH OF THE POLISHED SECTION OF A FRACTURE BAR

PHASE - I



MELT # 2

ZN: 3.30%
RE: 1.95%
ZR: 0.76%
Magnification: 100x
Grain Size: 0.0012" (Approx.)

FIGURE - 8

WELD AREA FOR SEPARATELY CAST TEST BARS

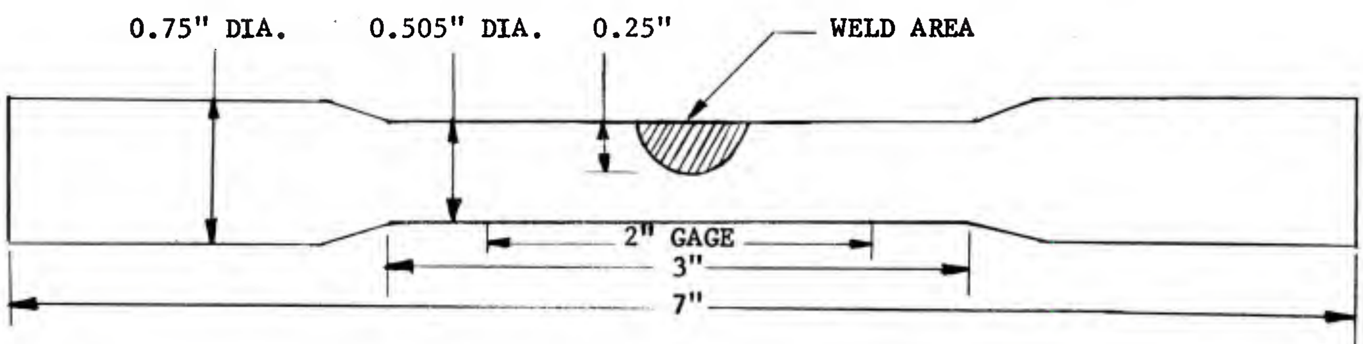


FIGURE - 9

PROCESSING OF HLH COMBINER HOUSING

Core Making and Assembly

Melting

Pouring

Sandblast

Sawing: Gates and Risers

Benching

Acid Clean

Pickle (Dow 1)

Zyglo

X-ray

Saw Casting in Two Halves

Preparation of Weld Areas

Welding (Preheat temperature: 600° F, when necessary)

(Reject) Clean and Dye Check Weld Areas

(Accept)

(Reject) X-ray Welds

(Accept)

Heat Treatment

Sandblast

Pickle (Dow 1)

Zyglo

Tensile Testing (Cut Bars)

TABLE - XII

SUMMARY TABLE OF WELD AREAS ON TWO HALVES OF HLH COMBINER HOUSING

The following is summary table for the weld areas for the HLH combiner housing. All the defects were cut out from both the sections and similar areas were cut out to have identical weld areas on both halves. The type of defect found in visual and fluorescent inspection is also given in the table. Typical weld areas are shown in the following photographs.

Weld Number	Size of The Weld: Length (inch) X Width (inch) X Depth (inch)	Section A	Section B
1	2 x 1 x 1	---	Shrinkage
2	1.5 x 1.5 x 1.5	---	Shrinkage
3	0.5 x 0.5 x 0.25	Shrinkage	---
4	1 x 0.5 x 0.1	Shrinkage	---
5	2" x 0.4 x Thru wall	Shrink crack	---
6	2 x 1 x 0.25	Shrink crack	---
7	1.25 x 1.25 x 1	Shrinkage	---
8	1 x 0.75 x 0.2	---	Shrinkage
9	1 x 0.7 x 0.5	---	Dirt hole
10	3.5 x 1.25 x 0.25	---	Shrinkage
11	1 x 0.5 x Thru wall	---	Crack
12	4 x 0.5 x 0.25	---	Shrink crack
13	3 x 1.25 x 0.25	Shrinkage	---
14	1 x 0.5 x 0.3	---	Dirt hole
15	0.7 x 0.5 x 0.4	---	Shrinkage
16	0.5 x 0.5 x 0.2	---	Dirt hole

FIGURE - 10

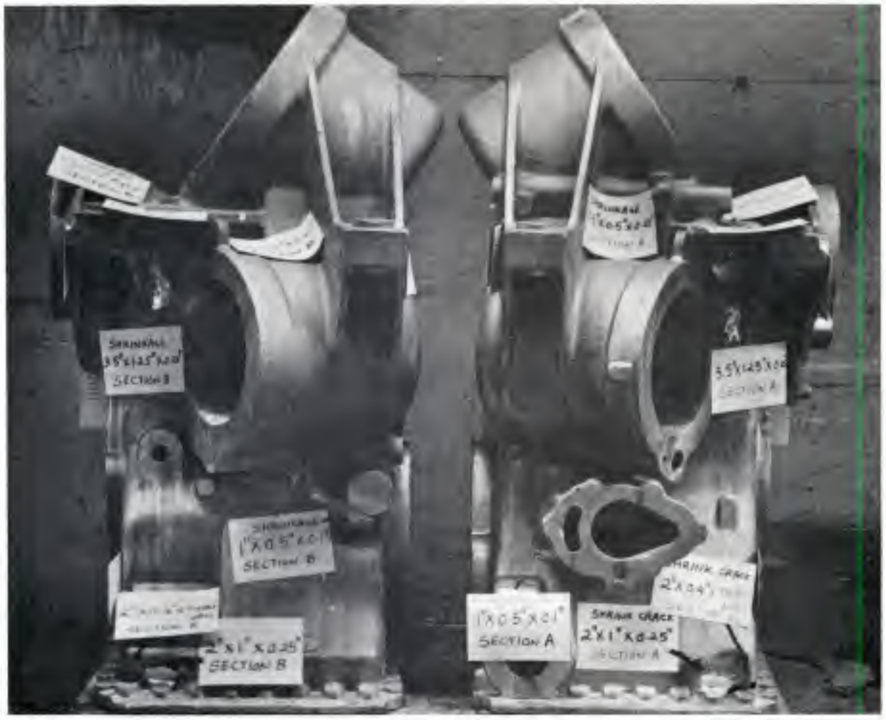
TYPICAL WELD AREAS ON TWO HALVES OF HLH COMBINER HOUSING

VIEW - 1

VIEW - 2

FIGURE - 11

TYPICAL WELD AREAS ON TWO HALVES OF HLH COMBINER HOUSING



VIEW - 3

VIEW - 4

TABLE XIII

SUMMARY OF MACHINED TEST BAR LOCATIONS FOR HLH COMBINER HOUSING

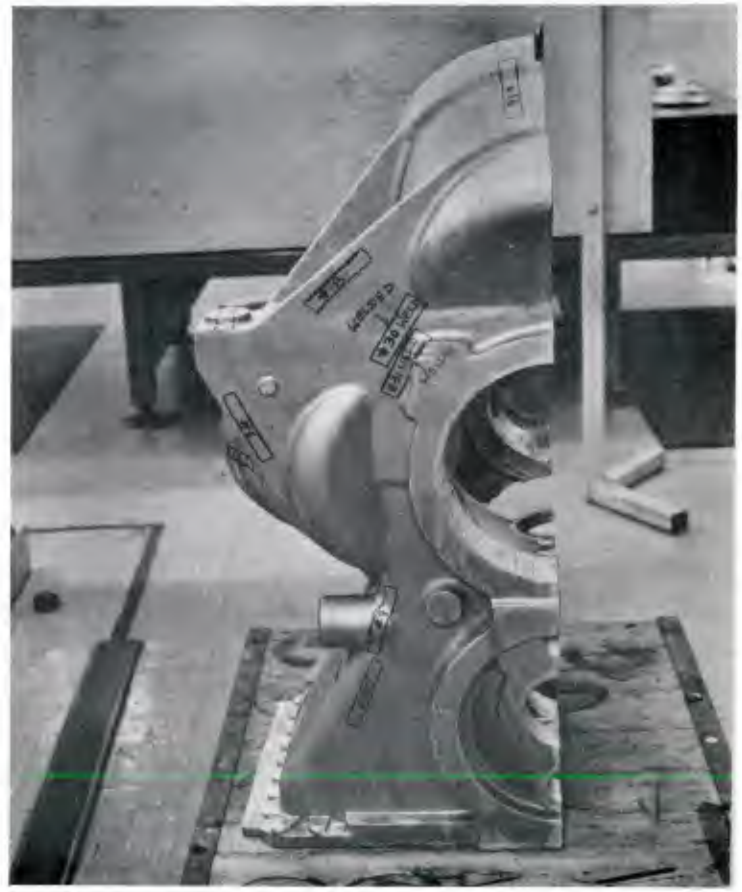
The following photographs are numbered. Refer to the following table to identify test bar locations.

View #	Test Bar Numbers
1	1, 2, 3, 5, 7, 11, 17, 21, 24, 25
2	6, 8, 10, 16, 30, 31
3	4, 9, 11, 17, 22, 23, 26, 29, 33
4	18, 19, 32, 34
5	20
6	27, 28
7	35, 36, 37, 38, 39

Refer to Table X for section thickness, chill/riser/neutral locations, tensile properties and other details.

FIGURE - 12
MACHINED TEST BAR LOCATIONS FOR HLH COMBINER HOUSING
SECTION B

VIEW - 1

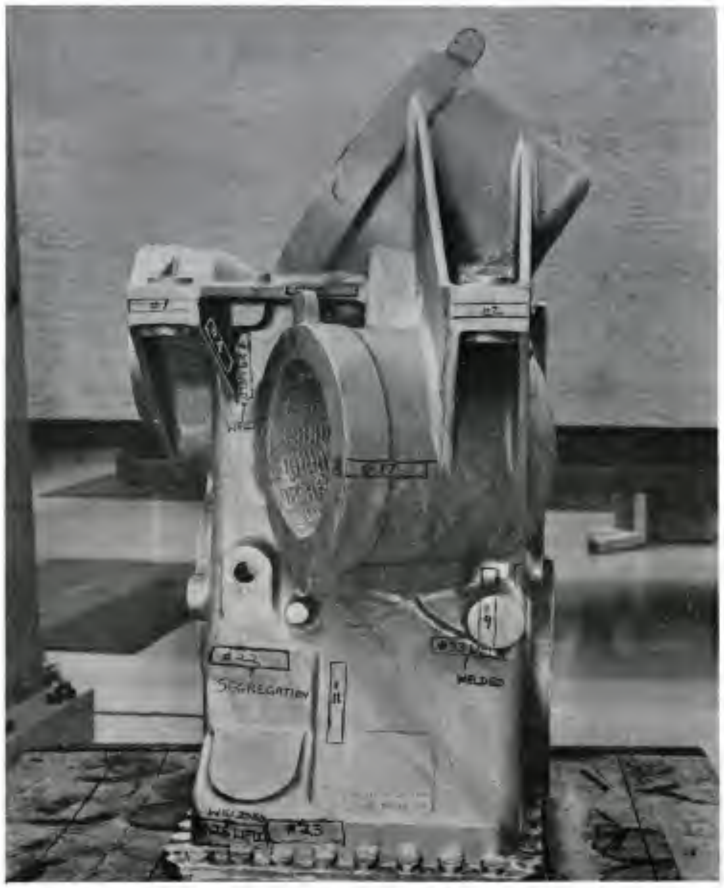


VIEW - 2

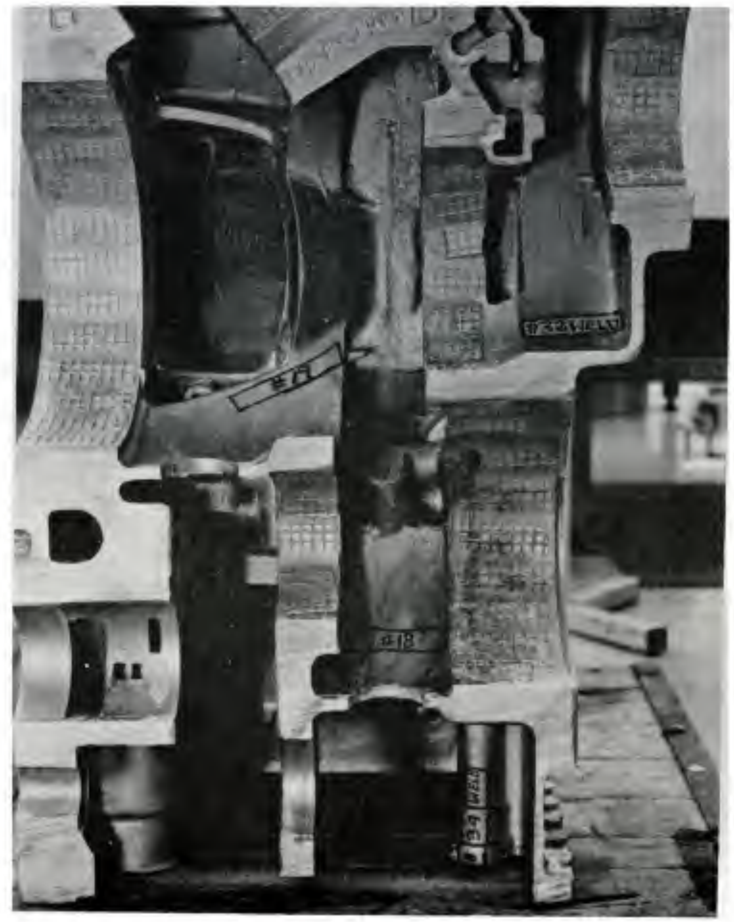
<u>FIGURE - 13</u>

<u>MACHINED TEST BAR LOCATIONS FOR HLH COMBINER HOUSING</u>

<u>SECTION B</u>



<u>VIEW - 3</u>



<u>VIEW - 4</u>

FIGURE - 14

MACHINED TEST BAR LOCATIONS FOR HLH COMBINER HOUSING

SECTION B

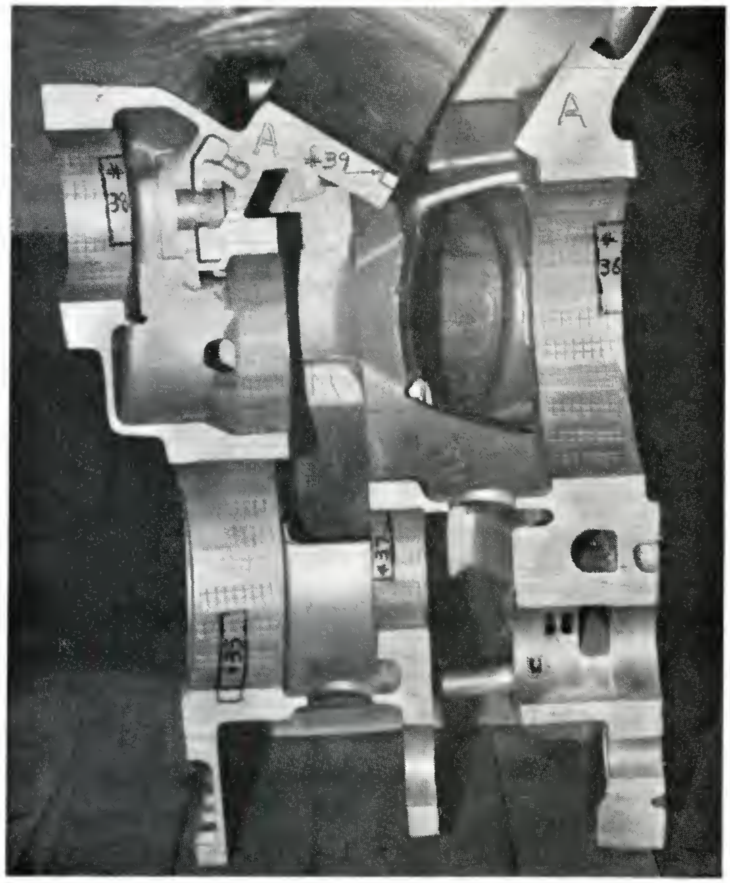
VIEW - 5

VIEW - 6

FIGURE - 15

MACHINED TEST BAR LOCATIONS FOR HLH COMBINER HOUSING

SECTION B

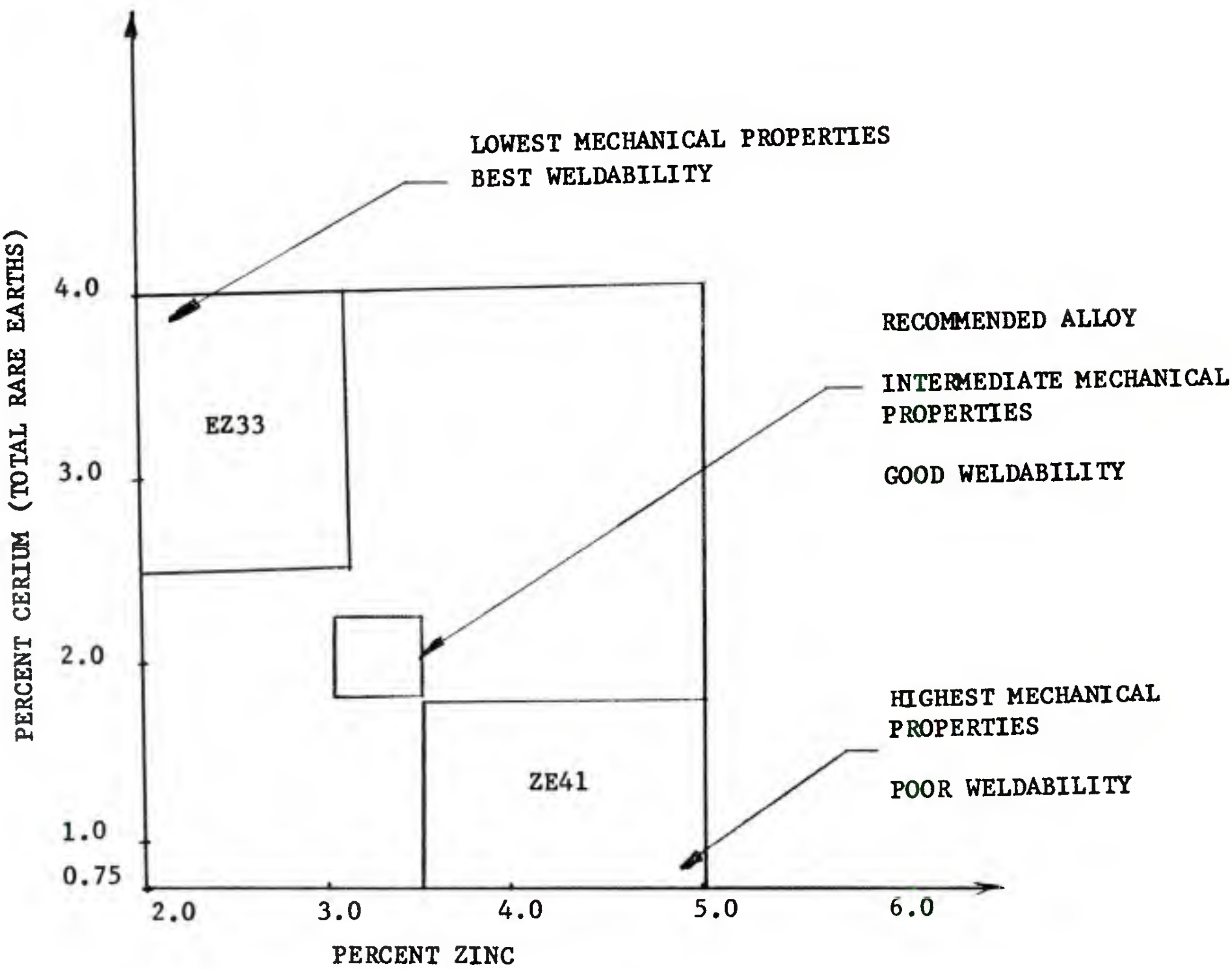


VIEW - 7

NOTE: These test bars were taken from similar locations on section B of the casting.

FIGURE - 16

SCHEMATIC REPRESENTATION OF THE EFFECT OF VARIATION IN CHEMICAL COMPOSITION ON TENSILE PROPERTIES AND WELDABILITY FOR ZINC-RARE EARTH-ZIRCONIUM TYPE MAGNESIUM ALLOYS



Low zinc and high rare earth chemical composition within ZE41 range also has good weldability, which is adequate for most castings of current design. The recommended alloy (recommended for large complex castings with intricate design) has better weldability and slightly lower tensile properties. Good weldability implies that the alloy is less prone to weld cracking.

FIGURE - 17

PHOTOMICROGRAPHS OF SELECTED TEST BAR LOCATIONS FROM HLH COMBINER HOUSING

APPENDAGE # 2
Nonwelded
Section thickness: 0.5"
Chilled

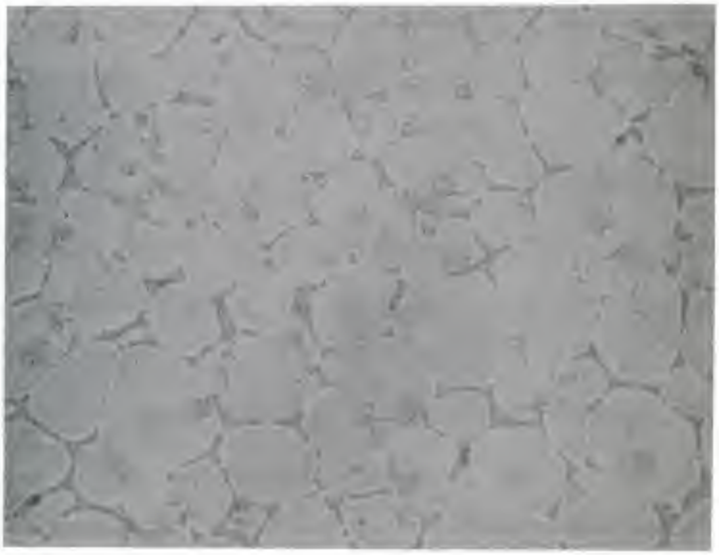
Location: Intermediate between riser and chill

100 X
Glycol etch
Grain size: 0.0025" (Approx.)

TEST BAR # 6
Nonwelded
Section thickness: 0.40"

Location: Neutral

100 X
Glycol etch
Grain size: 0.0020" (Approx.)



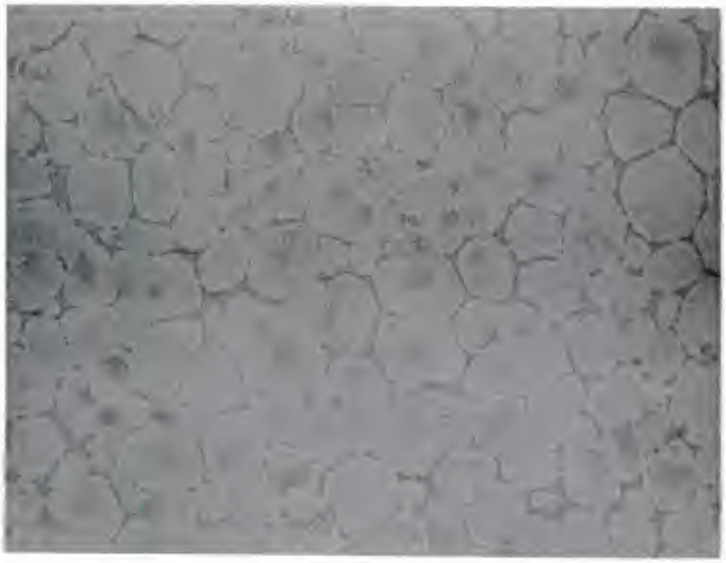
TEST BAR # 9
Nonwelded
Section thickness: 2.75"

Location: Riser

100 X
Glycol etch
Grain size: 0.0033" (Approx.)

FIGURE - 18

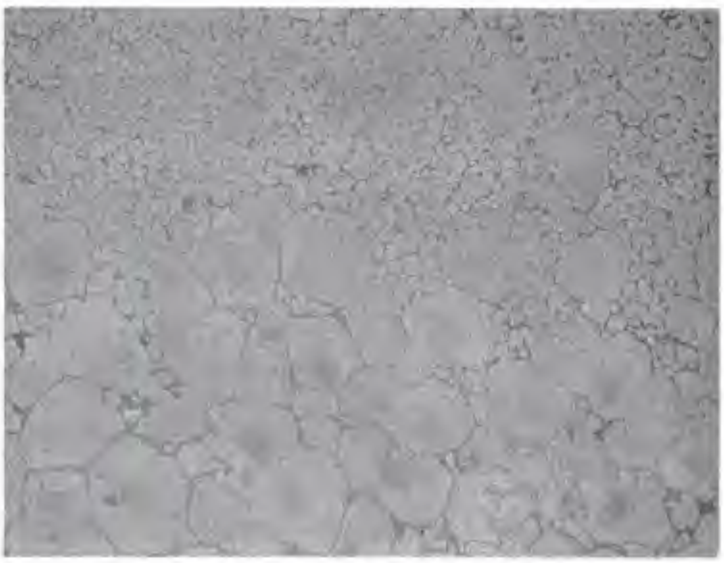
PHOTOMICROGRAPHS OF SELECTED TEST BAR LOCATIONS FROM HLH COMBINER HOUSING



TEST BAR # 23
Nonwelded
Section thickness: 0.45"

Location: Near riser

100 X
Glycol etch
Grain size: 0.0025" (Approx.)



TEST BAR # 24
Welded: Notice the fine grain size in weld area.

Section thickness: 0.35"

100 X
Glycol etch

TEST BAR # 31
Welded: Notice the fine grain size in weld area.

Section thickness: 1"

100 X
Glycol etch

TABLE I

SELECTED CHEMICAL COMPOSITIONS

MELT NO./ CHEMICAL COMPOSITION NUMBER	ZINC Min - Max	RARE EARTH Min - Max	ZIRCONIUM TOTAL Min - Max	MN. Max	CU. Max	NI. Max	IMPURITIES TOTAL Max
4-9435-1	3.0 - 3.5	1.5 - 1.9	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-2	3.0 - 3.5	1.8 - 2.2	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-3	3.0 - 3.5	2.1 - 2.5	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-4	3.5 - 4.0	0.75 - 1.25	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-5	3.5 - 4.0	1.25 - 1.750	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-6	4.0 - 4.5	0.75 - 1.25	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-7	4.0 - 4.5	1.25 - 1.750	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-8	4.5 - 5.0	0.75 - 1.25	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-9	4.5 - 5.0	1.25 - 1.750	0.7 - 0.9	0.15	0.10	.01	0.30
4-9435-10	4.25- 4.75	1.8 - 2.0	0.7 - 0.9	0.15	0.10	.01	0.30

NOMINAL COMPOSITION

MELT NUMBER	ZINC	RARE EARTH	ZR.
4-9435- 1	3.25	1.70	0.8
4-9435- 2	3.25	2.00	0.8
4-9435- 3	3.25	2.30	0.8
4-9435- 4	3.75	1.0	0.8
4-9435- 5	3.75	1.5	0.8
4-9435- 6	4.25	1.0	0.8
4-9435- 7	4.25	1.5	0.8
4-9435- 8	4.75	1.0	0.8
4-9435- 9	4.75	1.5	0.8
4-9435- 10	4.5	2.0	0.8

NOTES: (1) Maintain pouring temperature for test bars and test casting to within ± 50° F.
(2) Pour as close to the mold as possible.
(3) Pour two discs before and after pouring. Leave some melt at the bottom.
(4) Check Zr. grain refinement using fracture bars.

TABLE II

SELECTED HEAT TREATMENTS

IDENTIFICATION	TEMP (°F)	TIME (Hrs.)		TEMP	TIME
H1	625	2	Aircool	340	12
H2	625	4	Aircool	---	
H3	625	8	Aircool	---	
H4	625	12	Aircool	340	12
H5	625	20	Aircool	---	
H6	675	2	Aircool	340	12
H7	675	8	Aircool	---	
H8	675	12	Aircool	---	

TABLE III

AMS 4439 SPECIFICATION REQUIREMENTS FOR ZE41 ALLOY

Chemical Composition

	Min.		Max.
Zinc	3.5	-	5.0
Cerium (Total Rare Earths)	0.75	-	1.75
Zirconium, total	0.40	-	1.0
Zirconium, soluble (1)	0.40	-	--
Manganese (1)	--	-	0.15
Copper (1)	--	-	0.10
Nickel (1)	--	-	0.01
Other impurities, total	--	-	0.30
Magnesium	Remainder		

(1) Determination not required for routine acceptance.

Tensile Properties

PROPERTY	CAST TENSILE SPECIMENS	SPECIMENS CUT FROM CASTINGS	
		Average	Minimum
Tensile strength, PSI	29,000	28,000	26,000
Yield strength at 0.2 % offset, PSI	19,500	19,500	17,500
Elongation, % in 2 inch	2.5	2.5	2.0

TABLE I V

CHEMICAL COMPOSITIONS OF ACTUAL MELTS POURED

MELT NO ✓ CHEMICAL COMPOSITION NUMBER	DESIRED NOMINAL COMPOSITIONS			CHEMICAL COMPOSITIONS OF ACTUAL MELTS POURED		
	ZN	RE	ZR	ZN	RE	ZR
4-9435-1	3.25	1.70	0.8	3.08	1.62	0.78
4-9435-2	3.25	2.00	0.8	3.30	1.95	0.76
4-9435-3	3.25	2.30	0.8	3.12	2.38	0.75
4-9435-4	3.75	1.0	0.8	3.71	1.00	0.83
4-9435-5	3.75	1.5	0.8	3.71	1.45	0.74
4-9435-6	4.25	1.0	0.8	4.48	1.06	0.78
4-9435-7	4.25	1.5	0.8	4.28	1.47	0.79
4-9435-8	4.75	1.0	0.8	4.95	0.98	0.84
4-9435-9	4.75	1.5	0.8	4.74	1.59	0.81
4-9435-10	4.50	2.0	0.8	4.44	2.09	0.77

TABLE V

DEFECTS IN WELDED AREAS OF TEST PLATES - X-RAY RADIOGRAPHIC INSPECTION

PHASE - I

MELT No. \ WELD AREA No.	1	2	3	4	5	6	7	8	
1	3-C 2-D	6-C 2-D	3-C	1-C 3-D					
2	1-C 4-D	5-C 3-D					1-D		
3	4-C 3-D	4-C 3-D	1-D				1-D		
4	5-C	7-C	5-C				5-C		
5	5-C	8-C	3-C						
6	7-C	7-C	4-C				7-C		
7	5-D	5-C 2-D	2-C				3-C 2-D		
8	8-C	8-C	6-C				7-C		
9	4-C	8-C	1-C				6-C		
10	3-C 1-D	6-C	2-C				8-C		

NOTES: (1) See Figure 19, and Table VI for the explanation of weld areas of test plates. (1 through 8)

(2) Defect code: C: crack, D: dross (Foreign material, less dense.) Cracks vary in size. Dross appears as a single particle.

(3) Each melt has eight test plates. The above table indicates the total number of defects, (sum of the defects on eight test plates) in each of the eight weld areas for each melt.

(4) All the test plates had flow line type of eutectic segregation in weld area number 8, which resulted from multiple passes used for welding this thin area on the edge of the test plate. This defect does not have any detrimental effect on tensile properties. (See text for details.)

FIGURE - 19
IDENTIFICATION OF WELD AREAS OF TEST PLATE FOR
TABLE V

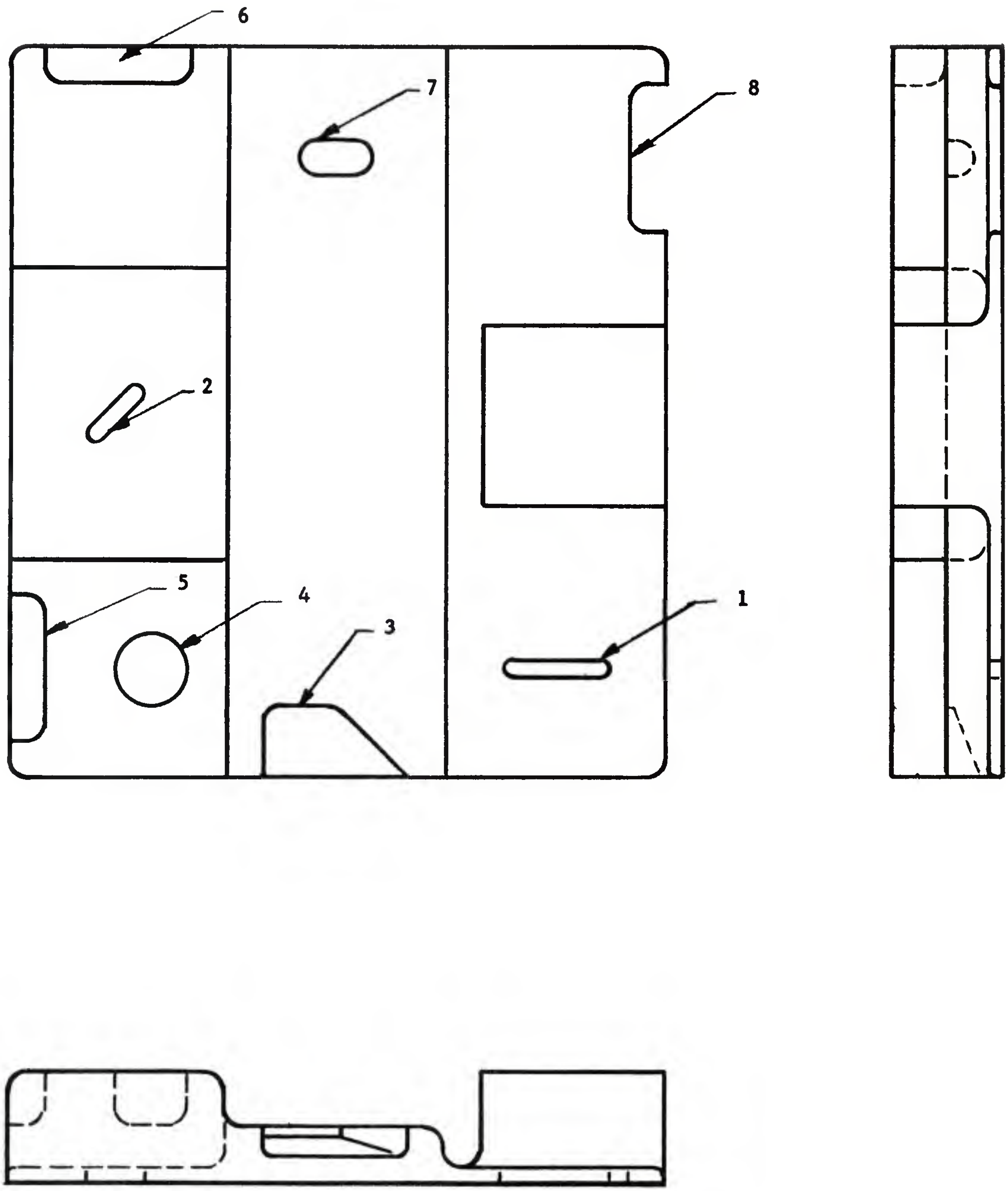


TABLE VI

EXPLANATION OF WELD AREAS OF TEST PLATE FOR

TABLE V

WELD AREA #	EXPLANATION
1	Thru the thickness weld in thin section: Heavy section on one side
2	Thru the thickness weld in thin section: Heavy sections on both sides
3	Intermediate section: Weld on the edge
4	Thick section
5	Thick section: Weld on the edge
6	Thick section: Weld on the edge
7	Intermediate section
8	Thru the thickness weld in thin section: Weld on the edge

Section	Thickness
Thin	3/16"
Intermediate	3/4"
Thick	1 1/2"

As can be seen from Table V, thin sections constrained by nearby heavy sections (weld number 1 & 2) are most prone to weld cracking and hence most difficult to weld. Tendency towards weld cracking increases with increasing zinc and decreasing rare earth content (that is increasing zinc/rare earth ratio).

TABLE VII

AVERAGE TENSILE PROPERTIES OF SEPARATELY CAST TEST BARS

(WELDED AND NONWELDED)

PHASE - I

HEAT TREAT NO. / MELT NO.		H1		H2		H3		H4		H5		H6		H7		H8	
		NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W
1	T.S. (PSI)	27,385	26,824	27,359	25,794	27,090	26,395	26,055	26,312	26,758	27,196	27,223	25,644	27,121	26,414	27,880	27,030
	Y.S. (PSI)	19,028	18,852	18,545	17,404	19,438	18,783	19,520	19,820	20,006	20,090	18,713	18,880	19,574	19,909	19,922	19,942
	% ELONG.	3.6	3.2	3.8	3.1	3.3	3.1	2.4	2.5	2.6	2.9	3.7	2.7	3.4	2.8	3.4	3.0
2	T.S. (PSI)	27,377	26,832	26,827	26,664	27,061	27,280	27,197	27,249	27,448	28,189	28,454	27,870	28,543	27,984	27,606	26,099
	Y.S. (PSI)	19,968	19,740	19,572	18,429	19,869	19,358	20,173	19,567	20,674	21,096	20,522	18,833	20,864	20,437	20,235	19,883
	% ELONG.	3.1	3.2	3.1	3.3	2.9	3.7	3.0	3.4	2.8	2.8	3.8	4.1	3.2	3.3	3.7	2.2
3	T.S. (PSI)	24,487	24,309	25,082	24,726	23,590	23,863	24,062	23,781	25,082	26,327	24,649	23,570	23,442	24,088	25,284	24,804
	Y.S. (PSI)	18,942	18,135	17,727	17,740	18,390	17,783	18,233	17,457	19,146	19,961	18,346	17,646	18,376	18,490	19,121	18,603
	% ELONG.	2.2	2.0	2.9	2.9	1.8	2.0	2.7	2.1	2.5	3.0	2.7	2.5	2.2	2.0	1.9	2.0
4	T.S. (PSI)	32,934	29,633	32,419	29,930	32,398	30,635	32,352	29,328	32,781	30,592	32,135	30,115	32,155	29,431	30,683	29,840
	Y.S. (PSI)	23,092	22,542	23,008	22,707	22,320	22,455	22,718	22,561	23,116	23,402	23,339	23,371	22,282	22,133	22,004	21,955
	% ELONG.	5.1	2.5	4.8	2.8	5.4	3.5	4.9	2.4	4.6	2.7	3.8	2.4	5.0	2.5	3.8	3.1
5	T.S. (PSI)	30,967	31,022	31,225	29,278	31,251	29,551	31,167	30,492	30,380	29,405	30,968	29,645	30,808	30,026	31,130	28,650
	Y.S. (PSI)	23,560	22,769	22,623	21,933	23,280	22,253	23,387	22,935	23,135	22,475	23,108	22,027	22,753	22,497	23,055	22,324
	% ELONG.	3.0	2.6	3.9	2.3	3.6	2.3	2.9	2.5	3.2	2.7	3.5	3.0	3.6	3.2	4.2	2.4

TABLE VII
(CONT'D)

AVERAGE TENSILE PROPERTIES OF SEPARATELY CAST TEST BARS

(WELDED AND NONWELDED)

PHASE - I

HEAT TREAT NO. / MELT NO.		H1		H2		H3		H4		H5		H6		H7		H8	
		NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W
6	T.S. (PSI)	32,578	31,197	32,693	29,444	32,756	28,455	32,246	28,635	32,688	28,080	32,366	28,099	30,922	28,928	31,473	28,420
	Y.S. (PSI)	25,169	26,131	22,727	22,182	23,162	22,123	23,703	22,761	23,135	22,187	23,314	22,675	21,516	21,108	22,433	21,281
	% ELONG.	3.7	2.2	3.7	2.3	5.4	2.4	4.4	2.1	4.5	2.6	4.2	1.5	4.2	2.6	4.8	2.5
7	T.S. (PSI)	31,898	29,318	31,549	29,794	31,323	28,959	30,351	28,117	30,878	28,558	31,909	30,386	31,188	27,600	29,810	27,680
	Y.S. (PSI)	23,730	23,009	22,546	22,002	23,185	22,823	22,771	22,979	23,540	22,577	23,534	23,884	22,637	21,730	22,545	21,541
	% ELONG.	3.4	1.7	3.7	2.8	3.5	2.0	2.8	1.5	3.1	2.0	4.2	2.7	4.0	2.0	3.0	1.8
8	T.S. (PSI)	34,922	30,023	33,894	28,452	33,633	29,414	33,108	29,676	33,745	30,193	32,967	29,679	32,072	28,753	32,273	28,735
	Y.S. (PSI)	26,289	24,182	23,845	22,696	23,286	22,880	24,745	24,097	23,831	23,242	24,994	24,541	22,695	22,591	22,739	22,557
	% ELONG.	2.8	1.7	4.7	1.5	5.4	2.1	3.8	1.8	5.3	2.9	4.2	1.6	4.3	2.4	5.1	2.3
9	T.S. (PSI)	32,354	28,940	31,407	27,869	32,892	30,497	33,135	29,002	33,028	30,903	32,717	29,479	31,850	30,260	31,990	28,976
	Y.S. (PSI)	24,980	23,843	23,847	22,492	23,670	22,930	24,451	23,381	24,497	23,357	24,199	23,578	23,217	23,190	23,165	22,988
	% ELONG.	3.7	2.0	3.5	1.5	3.8	2.4	4.1	1.9	3.8	2.9	3.6	2.0	3.4	2.8	4.0	1.9
10	T.S. (PSI)	27,640	28,057	27,363	26,605	27,729	28,192	28,104	25,350	28,025	27,250	27,682	26,809	27,721	28,549	26,943	26,313
	Y.S. (PSI)	21,588	21,386	22,437	20,948	21,295	22,432	22,199	21,537	24,354	23,756	23,671	22,477	21,757	22,027	22,543	21,635
	% ELONG.	2.4	2.5	2.0	1.6	2.2	2.2	2.5	1.1	1.9	1.5	2.2	2.1	1.7	1.5	1.2	1.8

NOTES: (1) See Table I and II for chemical compositions (1 to 10) and heat treatments (H1 to H8), respectively. W: welded test bars, NW: nonwelded test bars.

(2) Tensile properties for both welded and nonwelded test bars are an average of five test bars. Results with low tensile properties, resulting from the presence of discontinuities are not included in the averages.

TABLE VIII

AVERAGE TENSILE PROPERTIES OF TEST BARS MACHINED FROM WELDED TEST PLATES

PHASE - I

HEAT TREAT NO. / MELT NO.		H1		H2		H3		H4		H5		H6		H7		H8	
		NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W
1	T.S. (PSI)	28,313	27,952	27,315	30,326	27,668	25,983	28,148	26,158	29,238	27,164	28,805	25,879	27,827	28,055	25,637	27,115
	Y.S. (PSI)	19,344	19,096	18,786	20,033	19,380	19,845	19,786	20,485	19,662	19,860	18,964	19,294	19,396	19,305	18,116	18,783
	% ELONG.	3.4	3.0	2.9	4.2	3.3	2.0	3.3	2.2	4.3	2.8	4.4	2.5	3.0	3.2	3.6	3.3
	REMARK						Crack (one)										
	HARDNESS	62.2		59.7		60.5		61.3		63.4		60.9		59.8		60.5	
2	T.S. (PSI)	27,816	28,023	28,794	28,145	27,707	28,509	28,855	27,813	27,252	29,418	31,295	30,382	27,295	27,876	29,664	28,730
	Y.S. (PSI)	19,640	20,574	19,907	19,565	20,040	20,406	19,983	21,608	20,679	21,340	20,145	19,726	20,066	21,048	19,428	19,662
	% ELONG.	3.2	3.2	3.9	3.6	3.2	3.0	3.7	2.2	2.3	3.3	6.3	3.9	2.6	2.8	4.3	3.0
	REMARK																
	HARDNESS	61.3		61.7		62.9		62.2		60.9		60.6		62.9		60.5	
3	T.S. (PSI)	25,606	29,387	25,860	28,991	25,790	26,188	27,009	27,792	26,917	24,788	25,891	27,192	27,137	29,035	25,708	26,280
	Y.S. (PSI)	19,632	18,988	19,489	19,714	18,790	19,451	18,649	20,590	18,624	19,971	19,060	19,693	19,555	20,254	19,339	20,679
	% ELONG.	2.3	3.7	3.0	3.3	2.6	2.1	3.8	3.0	3.1	2.0	3.3	2.7	3.1	4.5	3.1	3.0
	REMARK		Crack (one)														
	HARDNESS	64.6		62.5		60.5		64.6		64.6		64.6		64.6		64.6	
4	T.S. (PSI)	33,744	30,368	32,926	29,035	29,113	28,336	30,830	30,671	31,605	25,322	29,297	29,408	31,649	32,540	33,313	27,287
	Y.S. (PSI)	23,154	20,063	22,443	21,329	20,588	20,712	22,274	22,274	22,437	20,231	19,970	19,628	22,303	21,627	21,595	20,226
	% ELONG.	5.9	3.7	4.1	2.1	3.6	3.0	3.1	3.0	4.1	1.5	3.1	3.2	3.1	5.2	6.1	3.1
	REMARK												Crack (one)				
	HARDNESS	62.4		61.7		60.1		62.4		60.6		62.5		62.6		61.3	
5	T.S. (PSI)	29,525	29,780	29,796	30,260	28,848	30,151	29,721	30,827	30,272	31,175	29,566	27,220	27,975	27,247	29,519	29,474
	Y.S. (PSI)	21,932	20,234	21,400	20,790	21,462	20,719	22,423	22,068	21,266	20,489	21,675	20,476	21,134	20,125	21,680	19,671
	% ELONG.	3.0	3.5	3.1	3.0	3.3	3.8	3.0	3.5	3.1	4.0	3.1	2.1	2.6	2.6	3.5	3.5
	REMARK				Crack (one)				Crack (one)		Crack (one)						
	HARDNESS	63.4		63.8		62.2		64.2		62.9		62.6		64.2		65.0	

TABLE VIII
(CONT'D)

AVERAGE TENSILE PROPERTIES OF TEST BARS MACHINED FROM WELDED TEST PLATES

PHASE - I

		H1		H2		H3		H4		H5		H6		H7		H8	
		NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W
6	T.S. (PSI)	30,926	29,202	30,448	26,322	29,869	28,766	30,729	26,916	32,809	29,867	31,836	28,925	31,004	24,702	34,114	29,040
	Y.S. (PSI)	22,242	21,341	22,008	22,115	21,190	20,329	21,931	21,205	24,744	21,018	22,175	20,562	21,068	19,975	21,138	20,560
	% ELONG.	3.0	3.0	3.1	1.5	3.8	3.5	3.1	2.1	3.6	3.0	4.0	3.1	4.0	2.5	5.6	3.7
	REMARK				Crack (one)				Crack (one)		Crack (one)		Crack (one)		Crack (one)		
	HARDNESS	66.8		66.8		64.6		64.6		64.6		66.8		64.6		64.6	
7	T.S. (PSI)	32,820	27,250	34,718	27,937	34,314	31,454	34,175	32,419	32,833	29,661	31,807	23,689	34,734	26,103	33,695	24,217
	Y.S. (PSI)	22,872	20,532	22,466	20,517	22,333	18,213	22,343	18,514	22,081	19,824	21,785	17,771	21,955	20,472	22,080	18,254
	% ELONG.	4.0	1.8	7.8	2.5	5.2	4.5	6.0	5.5	4.6	3.7	5.0	1.5	6.5	2.8	5.5	2.2
	REMARK						Crack (two)		Crack (one)		Crack (one)		Crack (one)				Crack (two)
	HARDNESS	64.7		65.5		65.0		65.5		64.2		65.0		65.0		64.2	
8	T.S. (PSI)	32,625	29,253	31,795	26,801	30,621	32,727	34,655	30,277	34,071	29,323	34,773	31,999	30,836	26,815	31,847	29,508
	Y.S. (PSI)	23,630	20,083	21,210	22,013	21,788	21,600	22,648	21,104	22,398	21,688	23,895	20,970	21,127	20,666	21,475	21,639
	% ELONG.	3.1	3.0	4.1	2.1	3.0	3.0	4.6	2.8	4.3	1.8	3.1	3.3	4.5	2.7	5.0	4.0
	REMARK		Crack (two)		Crack (two)		Crack (two)		Crack (one)		Crack (one)		Crack (one)		Crack (two)		Crack (three)
	HARDNESS	69.1		66.8		66.8		66.8		64.6		66.8		64.6		64.6	
9	T.S. (PSI)	30,232	29,656	29,269	27,797	33,330	28,985	33,957	29,578	32,686	26,875	31,732	27,179	31,760	24,708	33,551	23,002
	Y.S. (PSI)	22,065	19,509	21,449	18,160	22,329	22,586	23,071	21,326	21,946	19,746	23,789	19,334	22,075	18,285	21,634	18,255
	% ELONG.	3.0	3.7	3.6	2.9	5.0	2.0	5.3	3.0	6.2	3.0	3.9	2.7	5.5	2.4	6.8	1.5
	REMARK		Crack (one)		Crack (two)						Crack (one)						
	HARDNESS	64.6		64.6		60.5		62.5		60.5		64.6		64.6		60.5	
10	T.S. (PSI)	30,952	24,600	30,712	29,155	29,450	29,776	28,281	27,810	30,172	27,692	28,518	28,805	30,105	28,530	28,757	29,445
	Y.S. (PSI)	22,044	21,623	22,334	21,261	22,058	21,486	19,884	20,857	21,781	19,392	21,750	22,459	21,321	20,315	21,670	20,652
	% ELONG.	2.6	2.5	2.6	2.3	1.9	2.8	2.6	2.0	3.8	3.0	2.3	3.0	3.6	2.7	2.3	3.3
	REMARK		Crack (two)														Crack (one)
	HARDNESS	69.1		64.6		64.6		60.5		66.8		66.8		66.8		64.6	

NOTES:
(1) See Table I and II for chemical compositions (1 to 10) and heat treatments (H1 to H8), respectively. W: welded test bars, NW: nonwelded test bars.
(2) Tensile properties are an average of four specimens for welded test bars and an average of three specimens for nonwelded test bars. Both welded and nonwelded test bars were taken from thin, thick and intermediate welded and nonwelded areas of the test plates. See Figure 20 for test bar locations and Table IX for explanation of test bar locations.
(3) Results with low tensile properties, resulting from the presence of discontinuities (Like cracks, inclusions, etc.) are not included in the average properties. Some welded test bars had cracks. Number of such cracks is indicated under remark. Other discontinuities are not shown in the above table.
(4) Brinell hardness was measured using 500 kg load and 10 mm ball.

FIGURE - 20
TENSILE TEST BAR LOCATIONS FOR TEST PLATE

AVERAGE TENSILE PROPERTIES FOR WELDED AND NONWELDED TEST BARS ARE GIVEN IN TABLE VIII

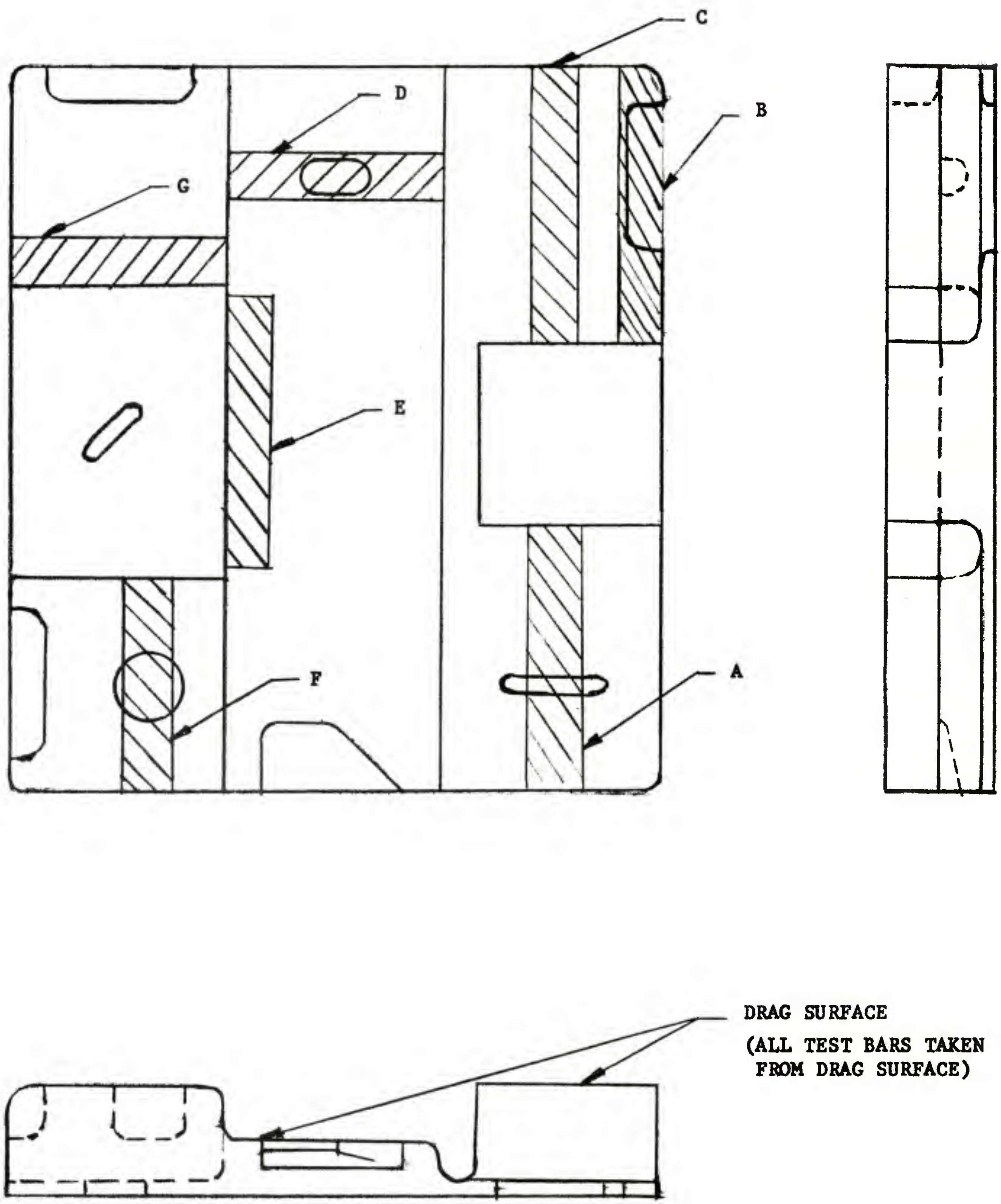


TABLE IX

EXPLANATION OF TEST BAR LOCATIONS FOR TEST PLATE SHOWN IN FIGURE 20

AVERAGE TENSILE PROPERTIES FOR WELDED AND NONWELDED TEST BARS ARE GIVEN IN TABLE VIII

TEST BAR LOCATION	EXPLANATION
A	Thin: Welded
B	Thin: Welded
C	Thin: Nonwelded
D	Intermediate: Welded
E	Intermediate: Nonwelded
F	Thick: Welded
G	Thick: Nonwelded

Section	Thickness
Thin	3/16"
Intermediate	3/4"
Thick	1 1/2"

TABLE X

TENSILE PROPERTIES OF MACHINED TEST BARS CUT FROM HLH COMBINER HOUSING

PHASE - II

Test Bar Number (Fig. 10)	Section Thickness (Inch)	Location: Chill/Riser/ Neutral	T.S. (PSI)	Y.S. (PSI)	Elongation (%)	Brinell Hardness (500 kg load, 10 mm. ball)
TEST BARS TAKEN FROM NONWELDED AREAS						
1	3"	Intermediate: Between Riser & Chill	24,221	15,015	3.0	51.8
2	3"	Intermediate: Between Riser & Chill	23,504	15,283	4.0	55.1
3	0.48"	Neutral	25,121	15,894	4.5	55.1
4	0.42"	Neutral	22,803	15,335	3.5	56.8
5	0.40"	Neutral	22,571	15,943	3.0	56.8
6	0.40"	Neutral	26,951	17,268	5.0	55.1
7	0.45"	Neutral	25,035	15,425	4.0	58.6
8	0.45"	Neutral	25,581	16,567	4.0	53.4
9	2.75"	Riser	21,183	15,261	3.0	55.1
10	0.31"	Neutral	23,326	14,903	3.0	56.8
11	0.30"	Neutral	24,111	15,353	3.5	55.1
16	1.21	Intermediate: Between Riser & Chill	24,489	15,472	4.0	55.1
17	1.3", 1.6"	Intermediate: Between Riser & Chill	25,560	15,432	4.0	58.6
18	0.4"	Neutral	24,903	14,929	4.0	53.4
19	0.3", 0.5"	Neutral	22,916	15,000	3.5	56.8
20	0.3"	Neutral	25,153	15,000	4.0	53.4
23	0.45"	Near Riser	27,557	16,941	5.5	55.1
TEST BARS TAKEN FROM SEGREGATION AREAS						
21	0.35"	Near Riser	23,513	15,176	3.5	56.8
22	0.35"	Neutral	23,750	16,590	3.0	55.1

TABLE X
(CONT'D)

TENSILE PROPERTIES OF MACHINED TEST BARS CUT FROM
HLH COMBINER HOUSING

PHASE - II

Test Bar Number (Fig. 10)	Section Thickness (Inch)	Location: Chill/Riser/ Neutral	T.S. (PSI)	Y.S. (PSI)	Elongation (%)	Brinell Hardness (500 kg load, 10 mm. ball)
TEST BARS TAKEN FROM WELDED AREAS						
24	0.35"	---	21,460	15,241	3.5	53.4
25	0.27"	---	24,755	16,447	3.5	56.8
26	0.35"	---	24,275	14,190	3.5	55.1
27	2.0"	---	22,900	16,779	3.0	56.8
28	0.62"	---	25,707	16,156	4.0	58.6
29	1.60"	---	23,471	15,834	4.0	55.1
30	1.0"	---	22,609	16,119	2.5	58.6
31	1.0"	---	22,973	16,565	2.5	53.4
32	0.45", 1.5"	---	26,887	16,500	4.0	53.4
33	0.3"	---	26,439	16,979	4.5	55.1
34	0.4",0.6",0.8"	---	26,682	15,981	5.0	53.4
TEST BARS TAKEN FROM CHILLED AREAS						
35	1.3"	Chill	25,965	17,109	2.0	58.6
36	1.5"	Chill	24,924	14,591	4.0	58.6
37	1.0"	Chill	25,680	15,648	4.2	56.8
38	1.8"	Chill	23,517	16,550	2.0	56.8
39	1.25"	Chill	24,576	16,525	4.0	56.8
TEST BARS MACHINED FROM CAST APPENDAGES						
--	0.5"	Chill	27,088	15,527	5.0	--
--	0.5"	Chill	27,313	15,723	6.5	--

TABLE X
(CONT'D)

TENSILE PROPERTIES OF MACHINED TEST BARS CUT FROM
HLH COMBINER HOUSING

PHASE - II

AVERAGE TENSILE PROPERTIES OF VARIOUS AREAS

Test Bar Location	AVERAGE TENSILE PROPERTIES T.S. (PSI)	Y.S. (PSI)	ELONGATION (%)
Nonwelded Areas	24,410	15,590	3.8
Segregation Areas (detected in x-ray)	23,632	15,883	3.2
Welded Areas	24,378	16,072	3.6
Chilled Areas	24,932	16,085	3.2
Cast Appendages	27,201	15,625	5.7

NOTES:

(1) See Figures 12 to 15 for test bar locations.

(2) Tensile properties of test bars taken from thick sections and riser locations are slightly lower than thin sections and chilled locations. But, in general, the tensile properties of different test bars are quite similar.

(3) (a) All the nonwelded test bars were taken from the middle of the section thickness.

(b) All the welded test bars were taken from the weld surfaces.

(c) All the chilled test bars were taken from the chilled surfaces.

TABLE XI

TENSILE PROPERTIES OF TEST BARS MACHINED FROM AREAS OF TEST PLATE CONTAINING FLOW-LINE TYPE OF SEGREGATION

Flow-line type of segregation resulted from welding of a thin area on the edge of the test plate using multiple passes (weld area number eight (8) in Figure - 19). Tensile properties of the test bars machined from this area are given below, along with the tensile properties of test bars machined from an adjacent nonwelded, sound area of identical thickness. The following results are for eight different heat treatments (Table II), for chemical composition number 5 (Table I).

HEAT TREATMENT	DEFECTIVE AREA (Flow-line Segregation)			DEFECT FREE, SOUND AREA		
	T.S. (PSI)	Y.S. (PSI)	ELONGATION (%)	T.S. (PSI)	Y.S. (PSI)	ELONGATION (%)
H1	30,849	22,058	3.5	30,794	22,476	3.0
H2	30,260	20,790	3.0	30,369	22,860	3.0
H3	29,818	20,605	4.0	28,213	22,144	3.0
H4	28,850	21,818	3.0	30,135	22,642	3.0
H5	31,565	20,308	4.0	30,105	23,274	2.5
H6	30,026	21,841	2.5	27,218	22,740	2.0
H7	26,421	20,274	2.0	25,587	22,530	3.0
H8	31,973	20,043	5.0	28,404	22,340	3.5

DISTRIBUTION

Commander
US Army Armament Command
Rock Island IL 61201

Attn: AMXPE-MT,
G. Ney

Director
Air Force Materials Laboratory
Attn: AFML, Technical Library
Wright Patterson AFB
Dayton OH 45433

Commander
Wright-Patterson Air Force Base
Dayton OH 45433

Commander
US Army Material, Development &
Readiness Command
5001 Eisenhower Av
Alexandria VA 22333

1 Attn: DRCDE-A
L. Croan

1 Attn: DRCDMD

1 Attn: DRCDMR

1 Attn: DRCDMD-T

1 Attn: DRCDE-F
Foreign Science &
Technology

1 Attn: DRCDE-W

1 Attn: DRCMT

Commander
US Army Ballistic Research Lab.
Aberdeen Proving Ground MD 21005

Attn: Technical Information Div.

Commander
US Army
Eglin Air Force Base
FL 32542

Attn: AFATL-DLOU,
A. Lopez

Commander
Picatinny Arsenal
Dover NJ 07801

1 Attn: SARPA-AD

1 Attn: Technical Information Division

Commander
Watervliet Arsenal
Materials Engineering Division
Watervliet NY 12189

Attn: Technical Information Division

Commander
Andrews Air Force Base
MD 20331

1 Attn: Hq AFSC-SDW,
R. W. Hartmeyer

1 Attn: Hq AFSC-INA

Commander
Air University Library
Maxwell Air Force Base
AL 36112

Commander
Rock Island Arsenal
Attn: Technical Information Division
Rock Island IL 61201

Commander
Army Materials & Mechanincs
Research Center
Watertown MA 02172

Attn: Technical Information Div.

Commander
Office of Naval Research
Dept. of the Navy
Attn: 423
Washington DC 20025

Commander
US Army Research Office
PO Box 12211
Attn: Dr. George Mayer, Director
Metallurgy & Materials
Science Division
Research Triangle Park
NC 27709

Commander
Naval Air Development Center
Johnsville, Aero Materials Dept.
Attn: Mr. Forrest Williams
Warminster PA 18974

Aerospace Corporation
Attn: E. G. Kendall
El Segundo CA 90245

Director
National Academy of Science
Attn: Materials Advisory Board
2101 Constitution Av NW
Washington DC 20418

Metals & Ceramic Information Center
Battelle Memorial Institute
505 King Av
Columbus OH 43201

Defense Documentation Center (5)
Cameron Station
Alexandria VA 22314

Commander
Frankford Arsenal
Philadelphi PA 19137

1 Attn: SARFA-TD

1 Attn: SARFA-CE

1 Attn: PD

1 Attn: PD, Mr. G. White

3 Attn: PDM, J. D. Corrie

1 Attn: PDM-A, A. Gallaccio

7 Attn: PDM-P, R. E. Edelman

3 Attn: SARFA-TSP-L/51-2
1-Reference copy
1-Circulation copy
1-Tech Rpts Editing

Commander
US Army Aviation Systems Command
PO Box 209
St. Lousi MO

15 Attn: DRSAV-LEP
J. Thorp

1 Attn: DRCPM-IAP-T
J. Chevalier

1 Attn: DRSAV-EQA
W. McClane

Mr. John Fody
P38-21
Boeing-Vertol Company
Box 16858
Philadelphia PA 19142

Mr. Irian S. Reasor, Jr.
Bell Helicopter Textron
Dept. 81 PLT5A
PO Box 482
Ft. Worth TX 76101

Mr. Glenn E. Lattin
Chief, Materials Engineering
Sikorsky Aircraft
Stratford CT 06602

Mr. John C. French
Hughes Helicopters
Division of Summa Corp.
Centinela Av at Teal St
Culver City CA 90230

Mr. Jeremy J. Walters
Manager, Materials Lab.
AVCO Lycoming Division
550 S Main St
Stratford CT 06602